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Leveraging Open Source Development Value to Increase Freedom of Movement of Highly Qualified Personnel

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Abstract. It is now well established that a nation's university-educated highly qualified personnel (HQP) population has a clear positive benefit on economic development by improving labor force efficiency and productivity. Yet HQP mobility is often restricted, particularly for economically-poor undocumented HQP. In order to overcome the challenges of mobility for both traditional and undocumented HQP, this study evaluates how the use of open source (OS) development and documentation can overcome barriers to HQP mobility to benefit society. Case studies are provided for software and hardware. Then mechanisms of incentives for OS development to benefit the global commons are evaluated against the case studies. The results show that even modest contributions to open source development can result in substantial value and high societal ROIs, which are more than enough to justify funding HQP mobility by all three mechanisms. The ROIs for popular free software can range into the millions of percent, while for free and open source hardware the ROI is still high, but more modest (>10-1,000%) and more closely tied to the market value of the product. The mechanisms introduced in this study could serve as tools to reward OS contributions by HQP and grant them greater freedom of movement.

Keywords: *open source; HQP; immigration; economic development; open hardware; highly qualified personnel*

1. Introduction

The term 'highly qualified personnel' or HQP has historically referred to the educated elite of a country – those with at least a bachelors' degree or higher level of educational attainment. It is now well established from decades of international analysis that increasing the size of a nation's HQP labor force and the concomitant training system has a clear positive effect on economic development and that science and technology training of HQP in particular are valuable forms of human capital that improve labor force efficiency and productivity (Schultz, 1961;1963; Jones, 1971; Blundell, et al.,1999; Psacharopoulos, 1981; 1985; 1994). In modern knowledge-based economies, the inter-country movement of HQP brings value as they supply work-shortages in the receiving country, as well as increased knowledge to their home country on return (Gera & Songsakul, 2005). At a larger scale, the mobility of HQP not only benefits the global economy, but can also improves efficiency in receiving and sending institutions or countries since it reduces the duplication in research and development (R&D) (Gera & Songsakul, 2005). Wadhwa et al. showed that not only do foreigners play an important role in creating value for firms, but that more than 25% of technology related companies established between 1995 and 2005 in the U.S. had an immigrant as a key founder (2007). Aside from benefiting the receiving country, the flow of immigration strengthens the bilateral trade between skilled workers' source county and receiving country (Jansen & Piermartini, 2009). Temporary migrants have more impact on reducing transaction costs in bilateral trade compared to permanent migrants because their knowledge is more up-to-date (Jansen & Piermartini, 2009). International mobility also promotes the concentration of public science in the sending country since those visiting scientists engaged in knowledge and technology transfer (KTT) between the firms in their source countries and foreign institutions serve as a driver for increases in scientific and technical human capital in their home countries (Edler et al., 2011). Research as also found a positive impact of foreign skilled workers on industrial and public knowledge, and that international HQP boosts the average productivity of their domestic peers (Bosetti et al., 2015).

Despite these benefits of HQP mobility, policies often restrict them. For example, in the United States of America (U.S.) in 2004, the cap of H1B applications was decreased from 195,000 to 65,000, which greatly deterred the employment of some HQP from other countries (Mayda et al., 2018). The cap for H1B applicant in fiscal year 2021 is still 65,000 with an additional 20,000 for applicants with a masters' degree or above, yet the number of applications received in fiscal year 2021 was 274,237 (USCIS, 2021). The current system also limits H1B applicants' mobility as employers must pay fee to sponsor foreign workers' paper work every time they change jobs, which results in market underestimation of fair salaries for effected positions (Trimbach, 2016). Due to limited mobility of hired H1-B applicants, they are willing to work for a lower wage in order to stay in the receiving country and because of this, natives can be displaced by over-qualified international workers (Hira, 2007). This further prevents native workers from entering the market as the suggested wage shown are artificially low due to pressure from international workers

(Trimbach, 2016). It was found, however, that flow of immigrants post a minimum effect on wages and employment for the natives (Raphael & Ronconi, 2007). Rodrik thus argues that the U.S. government spent too many resources on preventing potential immigrants from entering the U.S. (2002). To benefit a home country's economy, an incentive for skilled workers to return to their home country is needed, and when the policy is too restrictive, immigrants do not tend to go back to their home country, which stagnates the economic growth of the home country (Ouaked, 2002). Ideally such stagnation is avoided so the general education level is raised by receiving skilled workers returning from destination countries to help the development of the source country (Ouaked, 2002). Not only do strict policies limit the mobility of skilled workers in the destination country, the existence of such immigration controls also generates the impression that foreigners are different and should not be integrated, which may cause unnecessary social problems (Pécoud & Guchteneire, 2006). Kato & Sparber found that the restrictive policy on H1-B visa posts a negative effect on incoming high-quality international students, as shown by a decline in international applicants' score on standardized tests, and this negatively affect the class experience of native university students (2011). It is clear that states ought to work together to build connections between each other instead of barriers to complicate the integration of all nationals, and eventually reaching a win-win situation for both sending and receiving countries (Wickramasekara, 2008).

Although allowing freedom of movement of HQP has been shown to be beneficial for a country's economy and development, there are many individuals that can not even use the current system. These 'undocumented HQP' lack access to capital and educational verification to even be considered in the sub-optimal processes discussed above. Wealthy undocumented HQP can obtain visas by investing in a company that guarantees a certain number of jobs. For example, in the U.S., other than applying for a green card while under H1B visas, foreigners are eligible to apply for a green card if the individual invests in a qualifying commercial enterprise without borrowing with a minimum capital investment of $1.8 million or $0.9 million in a high-unemployment or rural area, considered a targeted employment area. In addition, this investment is required to provide 10 full-time jobs for U.S. citizens, lawful permanent resident, or other immigrants authorized within two years (Immigrant Investor Visas, 2021). Poor undocumented HQP do not have the capital for this option as the primary reason they lack documentation is from the cost of formal schooling (Breno et al., 2017; Wiley et al., 2012).

In order to overcome the challenges of mobility for both traditional HQP and undocumented HQP, this study evaluates the use of open source (OS) development to overcome barriers to HQP mobility, which in turn can benefit all of society. First, OS is defined and means for quantifying the value of contributions for OS development are reviewed for both individual developer-based projects and mass-collaboration-based projects using case studies as examples for free and open source software (FOSS) and hardware (FOSH). Then three mechanisms are investigated to offer incentives for OS development to benefit the global commons: i) NPO funding of a visa from a percent return from OS savings, ii) treatment of OS developers as an investor-class immigrant to pay them back for past contributions, and iii) ROI for OS development used to justify direct investment at the national scale. The results of the values and ROIs for the case studies are applied and the implications of applying these mechanisms to OS development and HQP mobility in the context of freedom of movement policy are discussed.

2. Methods

2.1 Means of Quantification of Value of OS

Free and open source software (FOSS) is available in source code (open source) form, and can be used, studied, copied, modified and redistributed without restriction, or with restrictions that only ensure that further recipients have the same rights as those under which it was obtained.

With the majority of large companies now contributing to open source software projects (LeChair, 2016), it has become a dominant form of technical development because it is superior form of technical development (Raymond, 1999; Lee et al.,. 2009; Herstatt, C. and Ehls, 2015). 100% of supercomputers (Vaughan-Nichols, 2018) and 90% of cloud servers run open source operating systems (i.e. Facebook, Twitter, Walmart, Wikipedia, Yahoo, Youtube or Amazon use machines running FOSS) (Hiteshdawda, 2020). FOSS is used widely in the business world where 90% of the Fortune Global 500 use the open-source Linux operating system (Parloff, 2013). In addition, over 84% of the global smartphone market is open source, using Google's Android operating system (IDC, 2020), and more than 80% of the "internet of things" (IOT) devices also use FOSS (Eclipse, 2019).

Free and open source hardware (FOSH) builds on the same sharing philosophy and rights of users that underlies the success of FOSS (Powell, 2012; Gibb, 2014). As defined by the Open Source Hardware Association (OSHWA), FOSH is hardware whose design is shared publicly so that anyone can study, modify, distribute, make, and sell the design or hardware based on the design (2021). Thus, both FOSS and FOSH go beyond open access, granting users substantial freedoms to build on the intellectual work of others. FOSH provides the "source code" for physical hardware including the bill of materials (BOMs), schematics, computer aided designs (CAD), and other information such as detailed instructions needed to recreate a physical item. As well established in FOSS development, research-related FOSH is now demonstrating improved product innovation (Yip & Forsslund, 2017). FOSH is rapidly gaining momentum and trails behind the historical rise of FOSS by about 15 years (Pearce, 2018). Together FOSS and FOSH development will be referred to under the umbrella 'OS' term and the value of the OS development will be quantified by comparing OS products to proprietary commercial products of similar or lesser quality. A quantified value of OS development can be compared to the cost of HQP mobility.

2.1.1 Downloaded Substitution Value FOSS and FOSH Individual

In order for OS contributors to be identified and rewarded for the value they generate, the download substitution value method (Pearce, 2015) can be used to determine the minimum value of an open source product (either software (FOSS) or hardware (FOSH)) at a given time (t) by:

$$V_D(t) = \left(C_p - C_f\right) * P * N_D(t) \qquad [\$] \qquad (1)$$

Where C_p is the cost to purchase a commercial physical product for FOSH or for FOSS the commercial software cost to perform certain tasks. C_f is the marginal cost to fabricate the FOSH or use a FOSS (which will likely be zero, unlike hardware, as additional purchases are generally unnecessary to operate software). N_D is the number of downloads at a certain time given time, t. This value can be acquired from most OS repositories. P is the percent of downloads that result in actual application of the FOSH or FOSS. P is normally assumed to be 1, but there can be an error in P as downloading a design for a hardware or software code does not guarantee manufacturing of the FOSH or using the FOSS. On the other hand, a single download may potentially result in multiple fabrications and many software users by sharing via digital tools (i.e. emails, memory sticks or P2P websites). For cases where the

FOSS or FOSH can be a direct substitute for a single time purchased product the calculations are straight forward, particularly if a single contributor develops the open source product.

This approach becomes complicated in the case of software (and to a perhaps concerning trend in hardware as well) when users do not own the product. Instead individual users pay a monthly or yearly subscription fee. For example, Microsoft (2021) offers education plans for students from free to $6 per user per month with different accessibility and services, or for faculty members from free to $8 per user per month with different accessibility and services. Similarly for the various more specialized design and manufacturing software tools from Siemens (2020), the price ranges from $169 - $695 per month.

In these cases, the downloaded substitution value can be given by:

$$V_{DM}(t) = \left(C_M - C_f\right) * M * P * N_D(t) \qquad [\$] \qquad (2)$$

Where M is the number of months the software or hardware is used. M can be easily provided by the licensing provider if the software or hardware is operated online. If users' activities are not traceable when the OS product is being operated offline, M may be obtained by a survey sent out to a statistically-relevant number of the down-loaders whose emails are recorded upon downloading to determine the usage on this particular FOSS or FOSH. The frequency of usage does not influence the valuation of the OS product since paying a monthly does not necessarily mean a user will frequently use the product.

2.1.2 Value of contribution on mass collaboration projects

Equations 1 and 2 are straight forward for cases where an individual develops the entire FOSH or FOSS on his or her own. Many libre projects, however, are developed by teams of many individuals over long periods of time as developers built upon one another's work. To capture input efforts of an individual, the downloaded substitution value for an individual is given by:

$$V_{idv}(T) = \frac{T_{idv}}{T_{total}} * V_{DM}(t) \qquad [\$] \qquad (3)$$

T_{idv} represents the person-hour of a contributor. T_{total} represents the total amount of person-hour needed to develop the FOSS or FOSH assuming everyone's time is equivalent. This may be the case if, for example, the libre product is being developed by roughly equivalently skilled and dedicated people. There is precedence for thinking that everyone's time is equivalent (Jacob et al., 2004a;b). In most cases, even among specific types of developers, however, everyone's contributions are not equal (e.g. some programmers are faster than others and are less likely to make mistakes). In these cases, $V_{idv}(L)$ can be approximated by the pro-rated number of lines of code contributed:

$$V_{idv}(L) = \frac{L_{idv}}{L_{total}} * V_{DM}(t) \qquad [\$] \qquad (4)$$

L_{total} is the number of total source line of code written. L_{idv} is the number course line of code written by one contributor. This formula is only a first approximations, as it is well established that not all coders are equal (Bryan, 1994), some of the best code is efficient and uses few lines, however, that does not necessarily indicate the value of the code in the future. To maintain and reuse a code between different platforms, readability of a code is also an important factor to be considered (Tashtoush et al., 2013; Buse & Weimer 2010). Thus, the number of lines of code do not necessarily correlate with a developer's contribution. Somewhat ironically, Kozloski et al. (2019) filed a patent to record and analyze programmers' contributions in a collaborated environment using the cryptocurrency system Bitcoin uses to securely manage the data input and synchronize all the transactions to ensure no repeated transaction of codes are validated, which prevents double counting of similar input (although specific ways to quantify the contribution was not discussed).

Equation 4 could be further refined if considering how much error does one contributor's code has or how efficient that contributor's coding is in practice. The role system from Sensorica's benefit redistribution algorithm could be considered into this formula above, the more scarce one's skill is in a project, that person will get a higher multiplier based on his/her original amount of work of time-hour.

The contribution of an individual in a FOSS project could also be captured by the digital size of his/her input. This method will eliminate the disparities discussed earlier about the inequality in time effort. Error, however, is also present as different sections of code serves different purposes, some will inhabit a larger size just due to its role in the structure, etc. The value $V_{idv}(S)$ of an individual could be measure by:

$$V_{idv}(S) = \frac{S_{idv}}{S_{total}} * V_{DM}(t) \qquad [\$] \qquad (5)$$

Here S_{idv} is the digital size of a developer's input, and S_{total} is the digital size of the entire project measured in bytes.

Implementing the methods discussed above, it could be estimated how much work an individual has put in and what value he/she has created. This value is to be recorded for that particular contributor (i.e. HQP) and could be used with mechanism described in a later session to qualify this personnel and grant him/her privilege.

To further increase the attention on collaborative OS projects, Frangos et al. (2017) analyzed a collaboration between Sensorica, an online community base on peer to peer production and an academic laboratory. From Sensorica's Q&A session, they now offer money to the contributors if the project they join is already creating revenue, and they have a formula to estimate a role's contribution which will be introduced later in the article (Sensorica, 2021). If one contributor is more interested in social values, he/she can apply for grants to pay for their contributions towards the social impact they can produce (Sensorica, 2021). Sensorica also encourages redundancy in important roles so they can make sure there is always one person to react quickly to any upcoming challenges (Sensorica, 2021). To determine value Sensorica uses:

$$V_{Sensorica} = F * P * Ea(t) * Rep(t) \sum_i Ro_i \, C_i - \sum_j D_j \qquad [\$] \qquad (6)$$

Where F represents a measure of frequency of someone's contributions, the higher one's contribution occur, the higher F will be. P represents periodicity that measures the predictability of someone's contribution, the more predictable someone's work is, the higher this value will be. Ea measures the earliness of someone's engagement of a project and is a function of time. Rep measures the peer evaluated reputation as a function of time. Ro represents the role of a certain contributor, such as how complex is the skill performed by that individual and how much the project needs it, different type of jobs has a different rate for Ro. C represents any measurable contribution. D represents estimated damage, i.e. any penalty if one's work is not meeting a certain standard and becomes detrimental to a project. All of these factors are subjective to some degree, making the method extremely difficult to use in analysis for those external to a project. Although ROI is considered in Sensorica's discussion towards the algorithm, it can be observed that to distribute the revenue created by a project any potential social impact is not converted into some sort of currency and is also hard to achieve. In OS, many contributors are potential users of the product they are developing, The overall societal value of open source development is not captured by Sensorica's model, as it focuses primarily on paying developers from the revenue generated.

2.1.3 Return on Investment (ROI)

In the original determination of the ROI for developing open source products is given by (Pearce, 2016):

$$R_D(t) = \frac{V_D(t) - I}{I} \quad [\%] \quad (7)$$

where I represent the cost to develop a FOSH tool or FOSS. This can be augmented to provide the value as a function of monthly usage:

$$R_{DM}(t) = \frac{V_{DM}(t) - I}{I} \quad [\%] \quad (8)$$

Here, the interest in developing an ROI for society (R_{soc}), where the investment is not the development cost, but the cost to allow free motion of an FOSH/FOSS developer thus:

$$R_{socT}(t) = \frac{V_D(t) - I_{soc}}{I_{soc}} \quad [\%] \quad (9)$$

$$R_{socM}(t) = \frac{V_{DM}(t) - I_{soc}}{I_{soc}} \quad [\%] \quad (10)$$

Where I_{soc} is the social cost of allowing free movement to an OS developer. $R_{soc\,(T\text{ or }M)}$ measures the benefits a particular individual brings to the society and the cost to the society to make this individual mobile between countries. Social cost could be estimated by the average amount of money government spends on human services per taxpayer. According to the archives from the U.S. Office of Management and Budget (The White House, 2021), in 2021, the proposed budget for basic human services (e.g. social security, medicare, non-defense) is $3,689 billion and as the U.S. population is estimated to be around 330 million (U.S. Census Bureau, 2021) the cost of providing basic services to every taxpayer is $11,179. This provides the potential cost per year for each HQP admitted. Further the cost to admit one HQP to the U.S. can be estimated as a cost to admit one immigrant. In Simon's analysis, since immigrants do not have elderly dependents and children when they first settle, they appear as a surplus for the community as no services are claimed for their dependents while they contribute for the society (1984). Treating immigrant families as investments, which is a concept supported by Simon (1984), where they were considered an investment worth between $15,000 and $20,000 in 1984, using an average annual inflation rate of 2.52%, they are worth between $38,610 and $51,480 in 2021. This would indicate that the average immigrant is already a net positive ROI and this conjecture is supported by recent studies (Borjas, 1995; Barrett & McCarthy, 2007;Sherman et al. 2019). In the case described here the net benefit would be higher due to OS design value. It can be reasonably expected that HQPs will consume even less from public services than an average immigrant. Taxes towards education, elders, and medicare are less likely to apply in the case of a mobile HQP, so the estimated social cost of $11,179 used here is clearly an overestimation.

There are also administrative costs for governmental institutions to admit or send a single person. These costs are normally paid by the immigrant (e.g. the material and processing fee for a visa). For example, the visa to enter United States is $160 (U.S. Department of State, 2020) and will thus be ignored here.

In the simple case the partial value and partial ROI generated by one contributor could be obtained by:

$$R_{socT}(T,L,S) = \frac{\sum_i\left(\frac{T_{idv}}{T_{total}} * V_D(t)\right) - I_{soc}}{I_{soc}}, \frac{\sum_i\left(\frac{L_{idv}}{L_{total}} * V_D(t)\right) - I_{soc}}{I_{soc}}, \frac{\sum_i\left(\frac{S_{idv}}{S_{total}} * V_D(t)\right) - I_{soc}}{I_{soc}} \ [\%] \quad 11)$$

$$R_{socM}(T,L,S) = \frac{\sum_i\left(\frac{T_{idv}}{T_{total}} * V_{DM}(t)\right) - I_{soc}}{I_{soc}}, \frac{\sum_i\left(\frac{L_{idv}}{L_{total}} * V_{DM}(t)\right) - I_{soc}}{I_{soc}}, \frac{\sum_i\left(\frac{S_{idv}}{S_{total}} * V_{DM}(t)\right) - I_{soc}}{I_{soc}}$$

[%] (12)

The actual impact of ROI will be larger than only considering monetary terms with positive addition of social returns that further encourage the development of similar products. An OS developer may also work on multiple projects that will increase the value of ROI_{soc} he/she creates because it is the sum of all i. Though the value of the sum of all i can be conservatively as an underestimation which leads to a higher ROI_{soc}. Further evidence that this is an underestimate is the fact that knowledge spillover is commonly observed between collaborated projects and especially in open source development (although the level of spillover does not guarantee the success of a OSS project) (Fershtman & Gandal, 2011). Knowledge spillover is clearly present, however, they are not measured in the above equations. Thus, the ROI_{soc} calculated by the above equations is an underestimation.

Finally, it should be noted, that the download substitution value is an underestimation the value of an open source product as it can be safely assumed the item downloaded is used at least once and possibly more as well as the additional value of using it (e.g. when used for educational purposes (Schelly, et al., 2015), etc.). Long term future impact of OS projects should be weighted in addition to the current needs of them.

2.2 Case Studies

Popular open source software and hardware with reliable download statistics are chosen as case studies including: Apache Open Office (mass use software), FreeCAD (specialty software), and Open Shot (special-mass use) for FOSS. Similarly to FOSS, case studies are done for FOSH, where the value is estimated by equation (1). For FOSH a selection of simple consumer products was chosen that increased in complexity and price including a bottle opener, phone stand, bicycle phone holder, and glidecam. Next a high-end scientific / medical product was selected as an open source syringe pump and finally a disposable product: face shield. Download statistics for FOSS are obtained from SourceForge (SourceForce, 2021a), an open-source and business software distribution website. Download statistics for FOSH are obtained from YouMagine and MyMiniFactory (MyMiniFactory, 2021; YouMagine, 2021a), they are both open-source designs and 3-D design distribution websites.

3. Results

Using the methods outlined in section 2.1 the results of the caste studies selected in section 2.2 are detailed here.

3.1 Apache Open Office

Apache Open Office (Apache Open Office, 2021) is a leading OSS providing services similar to Microsoft 365 and other home office suite. Its total download count is 328,300,938 times on various platforms from 2011 to 2021 (SourceForge, 2021b). The monthly licensing fee for its equivalent software are found to be from $4 to $57 per month (Microsoft, 2021; Polaris, 2021; Zoho, 2021). Using equation (2), assuming all downloads result in at least one month of service (M=1, P=1), the range of savings generated is from $1,313,203,752 to $18,713,153,466. GitHub provides useful information regarding to the contribution of all participating developers. From the repository of Apache Open Office in GitHub, top 23 contributors have added 8,695,198 lines of code (GitHub, 2021a). The lines added by the top contributor is recorded to be 4,108,713 lines of code, which is 47.25% of total lines of code added. Using equation (4), the top contributor's effort in terms of saving is ranged from over $620 million to over $8.8 billion. For this contributor, his/her ROIsoc could be calculated by equation (10), which results in a ROIsoc ranged from 55,507% to 790,988%. The potential return on investment for society to support major contributors to any open source project are clearly enormous.

Alternative way to estimate the value represented by Apache Open Office is to treat every download as a full purchase of the equivalent software package. Most software companies release a new version in disk or as a CD key every year which functions permanently, but does not get updated like an online version. Retailers like Walmart or Best Buy distribute those 'hard copies' of software. For Microsoft Office 2019, the prices ranges from $130 to $250 with various additional services (Walmart, 2021). Using equation (1), while treating C_p as the cost to purchase a commercial product and C_f is zero since it is free to download and use the Apache Open Office. The resultant savings range from $42.7 billion to $82.1 billion. Inserting these values into equation (4), the top contributor's corresponding effort ranges from $20.2 billion to $38.8 billion, which results in a ROIsoc ranged from 1,804,009% to 3,469,248%! Again, these numbers are higher than before by two more orders of magnitude and probably closer to reality as most software users use core software like Office for more than one month.

3.2 FreeCAD

Do the same returns exist for specialty software? To probe this question, FreeCAD is used as a second example. FreeCAD is an open source parametric modeler (FreeCAD, 2021). Its download statistics are obtained from SourceForge to be 4,521,065 times from 2002-2021 (SourceForge, 2021c). The monthly licensing fee for equivalent software is found to be from $24.92 to $690 per month (AutoCad, 2021; NX, 2021). Using equation (1), assuming all downloads result in at least one month of service (M=1, P=1), the range of savings generated from $112,714,779.80 to $3,120,914,850. From the repository of FreeCAD in GitHub, the top 100 contributors have added 8,695,198 lines of code (GitHub, 2021b). The lines added by the top contributor is recorded to be 8,199,209 lines of code, which is 64.6% of total lines of code. Using equation (4), the top contributor's effort in terms of saving is ranged from $72,820,580.95 to $2,016,300,194.90. For this contributor, his/her ROIsoc could be calculated by equation (10), which results in a ROIsoc ranged from 6,513% to 180,364%. These values are not as high as with general purpose software, which is reasonable as to use those software require certain knowledge, but the number is still substantial. The alternative calculation based on one-time purchasing could also be applied on CAD software. Some CAD software companies offer a perpetual license, it is considered more expensive in a short period, but saves users money in a long run. Unlike an office suite, however, the functionalities of a CAD software changes more often. So perpetual licensed CAD software are not as common as other software (Darren, 2021). Equivalent CAD software that are still offering perpetual licensed product have prices ranging from $250 - $1,100 for CorelCAD and TurboCAD, respectively (CorelCAD, 2021; TurboCAD, 2021). Using equation (1), while treating C_p as the cost to purchase a commercial product and C_f is zero since it is free to download and use. The resultant savings range from $1.1 billion to about $5 billion. Inserting these values into equation (4), the top contributor's corresponding effort ranges from $730.5 billion to - $3.2 billion. Which results in a ROIsoc ranged from 65,349% to 287,537%.

3.3 OpenShot

OpenShot is an open source video editor that was first launched in 2008 (Openshot Video Editor, 2021). Its download statistics are partially reflected on SourceForge to be 14,715 time from 2020 to 2021 (SourceForge, 2021d). This download statistic is an unquestionable underestimation as it only includes less than on year. The monthly licensing fee for equivalent software ranges from $4.33 to $20.99 (Adobe, 2021; CyberLink, 2021). The one-time purchase price for equivalent application ranges from $99.99 to $139.99 (CyberLink, 2021). Using equation (2) with same assumption (M=1, P=1), the value for one-month usage case ranges from \$63,716 to \$308,868. Its repository in GitHub shows a total number of added line by top 31 contributors to be 10,250,778 lines (GitHub, 2021c). The top contributor is identified and the corresponding number of added lines is 8,719,690 lines. The top contributor's effort is calculated using equation (4), which ranges from \$54,199 to \$262,734 for monthly usage case and \$1,251,587 to \$1,752,272 for one-time purchase case. The corresponding ROIsoc is from 384% to 2250% for monthly-usage case and 11,096% to 15,575% for one-time purchase case. The study cases for median and average user is computed the same way and presented in the result section. Note the download statistics only recorded approximately one year of the transaction (2020-2021), but the software was launched in year 2008. This could explain the relatively low ROIsoc compared to other FOSS and FOSH.

3.4 Simple Consumer Devices

3.4.1 Smart One Handed Bottle Opener

Smart One Handed Bottle Opener was chosen for a FOSH study case of a common product. Its download statistics are obtained to be 7,888 times on YouMagine (YouMagine, 2021c). Its equivalent products are identified and their price ranges from \$2.99 to \$20 (Amazon, 2021a; Amazon, 2021b; GrabOpener, 2021). The amount of filament required to print this object is 12 g, using \$24.99 as the price of 1kg PLA filament, the corresponding cost to produce this object is \$0.30 (Hatchbox, 2021). Using equation (1), the value of this bottle opener ranges from \$21,219.67 to \$155,394.55. The corresponding ROIsoc for its designer is obtained by equation (9), which ranges from 89% to 1,290%.

3.4.2 Phone Stand

A 3-D-printable phone stand is a relatively common product, published on MyMiniFactory and downloaded 8,997 times (MyMiniFactory, 2021c). It takes 29g of filament to print, which results in a material cost of \$0.73 (Hatchbox, 2021). The commercial equivalent ranges in price from from \$4.99 to \$10.99 (Amazon, 2021c; 2021d). Using equation (1), the corresponding value of this phone stand ranges from \$38,374 to \$92,356. Its ROIsoc is calculated by equation (9), which ranges from 243% to 726%.

3.4.3 Bicycle Phone Holder

Similarly, a bicycle phone holder is a 3-D-printable design on YouMagine that has been downloaded 2,055 times (YouMagine, 2021d). The amount of filament required is 18 grams without and 21 grams with support which corresponds to $0.45 to $0.52 of a common PLA filament (HATCHBOX, 2021). The price of its commercial equivalent is between $13.99 to $29.99 (Amazon, 2021e; 2021f). Using equation (1), its corresponding value ranges from $27,671 to $60,705. Using equation (9), the ROIsoc is obtained and ranges from 148% to 443%.

3.4.4. Glidecam

Another popular design is a 3-D-printable glidecam, which represents a more specialized product, and has been downloaded 15,241 times (YouMagine, 2021e). Although only 191g of filament are needed for the part the designer suggests that 500 g will be needed because of supports and higher infill percentages. This quantity is used to calculate the lower bound of the value (YouMagine, 2021e). The other components like bolts, screws, and aluminum tube cost around $30 (AliExpress, 2021; Amazon, 2021g; 2021h), which makes the open source glidecam's costs between $66 to $799 (Amazon, 2021i; 2021j). Using equation (1), this produces a downloaded substitution value from $359,188 to $11,648,683 and using equation (9), the ROIsoc ranges from 3,113% to 104,101%.

3.5 Open Source Syringe Pump

An open source syringe pump (OSSP) was used as a specialty product. It wasdesigned on open source CAD software and can be manufactured by an open source 3-D printer, which results in a similar functionality of a commercial syringe pump with a cost of only 5% or less (Wijnen, 2014). The download statistics can be found on its online repository, 613 times on MyMiniFactory and 8,714 times on YouMagine (MyMiniFactory, 2021b; YouMagine, 2021b). The total number of downloads is N_D = 9,327 times. C_p, ranges from $260 - $1509 for a single pump and $1,800 - $2,606 for a dual pump (Wijnen, 2014). C_f, for the materials for a single OSSP is $97 and for the double OSSP is $154 (Wijnen, 2014). Assembling OSSP upon printing does not require any specific skills and it takes less than an hour. $10 is added into the cost for assembling. P is assumed to be one. Although a download does not guarantee a fabrication, the actual P could be significantly greater if digital file is exchanged without being recorded and fabricated in the end. This results in a value of $1,427,031 to $13,076,545 for single pumps and $15,258,972 to $22,776,534 for dual pumps. The online repository did not contain any information regarding to each co-author's contribution on OSSP, so the average value is given for each contributor to analyze their credit and ROIs. The average value for each contributor ranges from $356,758 to $3,267,114 for single pumps and $3,814,743 to $5,694,134 for dual pumps. The average ROIsoc ranges from 3,091% to 29,143% for single pumps and 34,024% to 50,836% for dual pumps. Overall the value shows that the value for specialized scientific and medical FOSH is relatively low compared to more general use FOSS. This hardware also requires advanced skills to both fabricate and use, which presents a barrier to technical diffusion.

3.6 Face Shields

Lastly, a protective face shield (protective visor) for use during the COVID-19 pandemic as personal protective equipment (PPE) designed by Eric Cederberg has been downloaded 74,482 times (YouMagine, 2021f). The amount of filament needed for the visor is around 14 grams, which is about $0.35 of PLA filament (Hatchbox, 2021). Price of a roll of clear vinyl used to attach on the 3-D printed frame is found to be $16.74, which is $1.51 per A4 size sheet for each face shield (ePlastics, 2021). The total cost for making a face shield is then $1.86. The commercial equivalent of this product cost between $3 to $9.95 (Amazon, 2021k; 2021l). Using equation (1), it produces a downloaded substitution value from $84,840 to $602,490. Using equation (9), the ROIsoc ranges from 659% to 5,289%. These values and ROIsoc are extreme underestimates, however, because during the pandemic many makers went into mini-mass-production to provide PPE for local hospitals and others.

3.6.1 Mini-Mass Production

The mini-mass production phenomena indicates a weakness in the assumptions used in the downloaded substitution value for all FOSH products. For PPE during the pandemic the issue is illustrated clearly. So far it has been assumed that P=1 for equation (1). This is seen in the case for the protective face shields in the first analysis. In the comment section of the design page, however, many users claimed they have printed multiple face shields. One registered user claimed the group he/she is associated with has printed close to 10,000 face shields, one other registered users also claimed he/she has printed more than 3,000 face shields personally (YouMagine, 2021f). A sub-case study case is thus done to estimate the value with those additional fabrications finding:

$$V_{\text{D-mult}}(t) = \sum_i (C_{pi} - C_{fi}) * P_i * N_{Di}(t) \qquad [\$] \qquad (13)$$

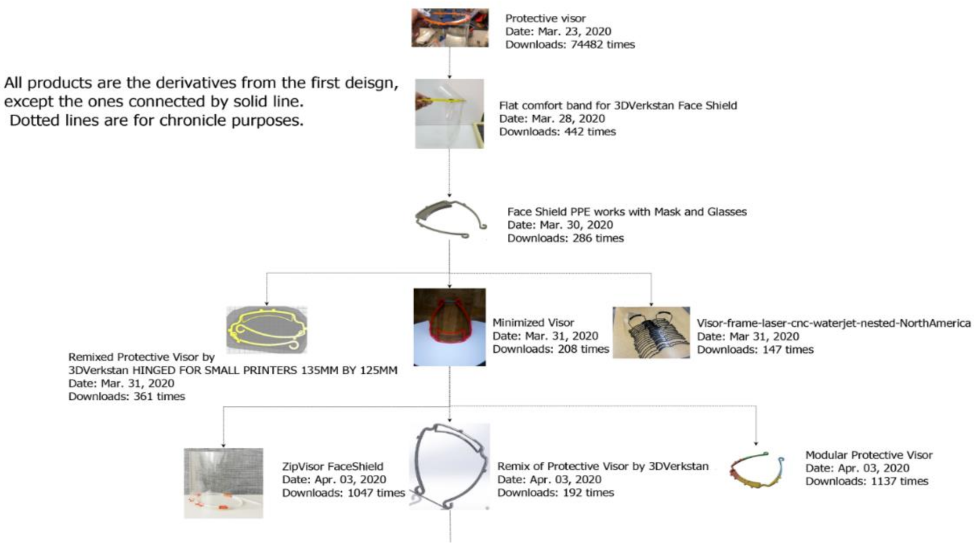
For the above case, the C_p and C_f will remain constant as $9 to $9.95 and $1.86. P will be one for the common case without registered information on how much they fabricated. P_2 and P_3 will be 10,000 and 3,000. N_{D2} and N_{D3} will be one, N_{D1} will be the total download times subtract by two, which is 74,480. The result value ranges from $99,645 to $707,631 using equation (13). The ROIsoc ranges from 791% to 6,230% using equation (9).

Figure 1. Examples of P>1 that were not able to be quantified (YouMagine, 2021f).

The above study case only included the additional amount of fabrication explicitly posted by registered users on YouMagine, there are many other users included picture of their fabrication yet did not specify the amount, thus, the obtained valuation here is also an underestimation (see Figure 1).

3.6.2 Derivatives of OS

OS projects are not only allowing users to download and use them at no cost, they also permit users to modify the existing file to improve or sometimes adjust the projects for a different environment. Take the examples from the case studies done above, the protective face shield designed has 26 derivatives recorded on YouMagine as shown in Figure 2 (YouMagine, 2021f). The original face shield design has been downloaded 74,462 times, all its derivatives have been downloaded 9,976 times, results in a total of 84,438 download times (YouMagine, 2021g). Most derivations are face shield with small improvements or adjustments for different types of printers. Other configured the original CAD in a way the face shields could be printed faster. One of the derivatives is a breaker tool that separates the face shields printed in a stack (YouMagine, 2021h). Verified users printed thousands of faceshields and it is possible some other medical or governmental organizations have printed even more without publishing the fact online. This would make the assumption of P=1 in the previous calculations to be a significant underestimation for both FOSH and FOSS, which could lead to a higher value and a higher ROIsoc for the developer.



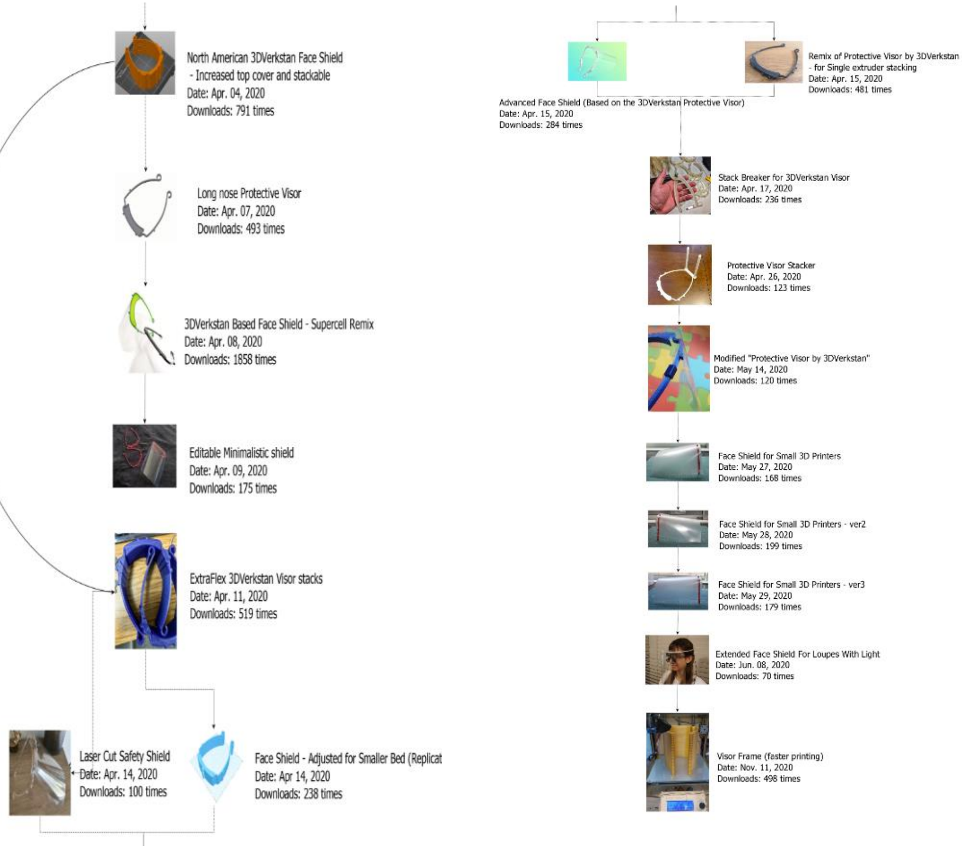


Figure 2. Derivatives of an open source face shield (Youmagine, 2021g).

3.7 Summary of Case Study Results

The case study of a FOSS is summarized in Table 1 for savings and ROI in Table 2.

Table 1: Estimated savings generated by chosen FOSS.

FOSS	Logo of FOSS	Downloads Statistics [times]	Data Collection Span [Year]	Estimated Savings [$]	Savings as one-time purchase [$]
FreeCAD		4,521,065	2002 - 2021	113m – 3.12b	1.13b – 4.98b
Apache Open Office	Apache OpenOffice™	328,300,938	2011- 2021	1.31b - 18.7b	42.7b – 82.1b

OpenShot		14,715	2021 - 2021	54,199 - 262,734	1.25m – 1.75m

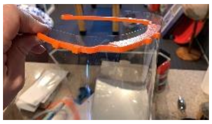
Table 2: ROI results summaries of case study FOSS projects.

FOSS	Target Contributor	Fraction of lines of code added [%]	Corresponding Savings [$]	ROIsoc [%]	One-time Purchase Savings [$]	One-time purchase ROIsoc [%]
Apache Open Office	Top	47.3	15.5m – 8.84b	5,550,699 – 79,098,784	20.2b – 38.8b	180,400,862 – 346,924,828
	Median	0.00716	94,089 – 1.34m	742 – 11,894	3.06m – 5.88m	27,254 – 52,054
	Average	4.35	57.1m – 814m	510,642 – 7,277,969	1.86b – 3.57b	16,599,005 – 31,921,257
FreeCAD	Top	64.6	72.8m - 2.02b	651,305 – 18,036,399	731m – 3.21b	6,534,863 – 28,753,739
	Median	0.0311	35,042 – 970,254	213 – 8,579	351,541 – 1.55m	3,045 – 13,736
	Average	1.57	1.77m – 48.9m	15,700 – 437,376	17.7m – 78.0m	158,406 – 697,326
OpenShot	Top	85.1	45,199 – 262,734	385 – 2,250	1.25m – 1.75m	11,096 – 15,575
	Median	0.000290	0.19 – 0.9	<0	4 - 6	<0
	Average	3.22	2,055 – 9,963	<0	47,463 – 66,450	325 - 494

Table 3 shows the case studies of the FOSH projects with the total value, values generated by an average developer and the ROI for society.

Table 3: Values and ROI for society for case studies of FOSH projects.

FOSH	Image of FOSH	Values generated from potential fabrication [$]	Values for an average developer [$]	ROIsoc [%]
Smart One Handed Bottle Opener		21,220 – 155,395	21,220 – 155,395	90– 1,290

Phone Stand		38,375 – 92,357	38,375 – 92,357	243 - 726
Bicycle phone holder		27,671 – 60,705	27,671 – 60,705	148 - 443
3-D-printable glidecam		359,188 – 11,648,683	359,188 – 11,648,683	3,113 – 104,101
Syringe Pump (Single)		1.43m – 13.1m	356,758 – 3.27m	356,758 – 3.27m
Syringe Pump (Dual)		15.3m – 22.8m	3.81m – 5.69m	3.82m– 5.69m
Protective Visor		84,840 – 602,490	84,840 – 602,490	659 – 5,289
Protective Visor (with additional fabrication)		99,645 – 707,631	99,645 – 707,631	791 – 6,230

To showcase the data from different perspectives, the median contributor among the selected developers is chosen to do the same calculation. Average contribution per developer of a selected group in a project is also simulated. It could be observed that the numbers for median and average contributor are significantly less than the top contributor, which is anticipated as there is not direct payback for those who work on OS if they are not on a paid position. Some people contribute more may because they have to frequently use the software and know what needs to be improved or because of altruism (Savikhin, Samek & Sheremeta, 2014).

4. Discussion

It is clear from the results summarized in Tables 1-3 that open source developers who may or may not be documented HQP can provide enormous value and ROIs for the societies that enable them to have free movement. As there is not currently a transparent direct payback to OS contributions, several mechanisms of incentives will be evaluated.

4.1. Mechanisms of incentives for OS development to benefit the global commons

4.1.1 Nonprofit funding of a visa from a percent return from OS savings

According to non-profit (NPO) websites volunteers are their main driving forces to maximize their impact towards the public (Bulman, 2018; National Council of Nonprofits, 2015). Mook et al. show that many contributions of volunteers in NPOs are not properly recorded (2005). This is in part due to the IRS (2021) claiming that volunteer time can not be officially reported. Recording the value of the time volunteering, however, could be used as an incentive. Revenues created by OS development for the NPO could even be used to fund mobility of HQP directly. James said that it is challenging to manage a NPO as they rely on profitable activities to raise funds for their non-profit activities (1983). This is why integrating OS with NPOs may be beneficial as OS will provide NPOs a wider access to spread their impact without spending as much funding to make that happen.

Engineering Without Border (EWB) is a non-profit organization with the aim to make a better world by fulfilling basic human needs worldwide (2021). EWBUSA's annual report (Financials, 2021) from 2018 shows they had a total revenue and support of more than $15 million, a total expense of more than $11 million, and a net assets of more than $4 million dollars at the end of year 2019 period with 707 underway projects (EWB, 2021). They had more than 16,000 volunteers working for them. Many of them work on appropriate technology development (Basu & Weil, 1998; Hazeltine & Bull, 2003), which could be leveraged as open source appropriate technology to make FOSH (Pearce & Mushtaq, 2009; Zelenika & Pearce, 2011;

Pearce, 2012). Although the IRS does not accept volunteer time as contributions on an official record (IRS, 2021), a better system could benefit both the organization and the volunteers without shifting the initial intention of volunteering. It is possible that volunteering could be leveraged as an incentive for a visa type document that grants a qualified personnel access to certain countries as well as work authorizations for them. NPOs would promote OS development activities people all over the world could participate in and indicate what potential benefits they could obtain. The NPO would be responsible to document record the contributions from the volunteers and estimate what value have they created using, for example, the methods outlined in this study. If this value exceeds a certain amount a visa or an equivalent is to be rewarded for that particular person.

4.1.2 Treatment of OS developers as an investor-class immigrant for past contributions

Foreign investors are eligible to apply for a U.S. green card if they invest in qualifying commercial enterprises without borrowing with a minimum capital investment of $1.8 million or $0.9 million in a high-unemployment or rural area, considered a targeted employment area. In addition, this investment is required to provide 10 full-time jobs for U.S. citizens, lawful permanent residents, or other immigrants authorized within two years (Immigrant Investor Visas, 2021). This policy created by the U.S. Congress to help stimulate the economy could be adjusted and implemented for global OS developers. One method is to calculate the percentage of code that is written by the OS developers and its value based on Section 2. Savings generated from using that OS code is matched to each contributor by their percentage of the work. Using this method, if the contribution of an individual is over the amount of money needed for the investment immigration program, then this contributor should be given a similar privilege. As can be seen in Tables 1-3 the values for some OS developers clearly could meet these criteria. A further restriction could go on measuring this person's future contribution towards similar OS areas.

4.1.3 Return on Investment

As can be seen by comparing Tables 1-3, the ROIsocs from FOSS are generally greater than the ones from FOSH. This is to be somewhat expected as not only does FOSS entail no material investment for a product, FOSS is much more mature and the use of computer software is far more ubiquitous than digital manufacturing. The ROIsoc for FOSS can be substantial. Consider Apache Open Office, where the ROIsoc ranges from 0.5 million to 32 million percent for an average contributor. Apache Open Office is comparable to a home office suite, it naturally has a greater user base. While more specialized FOSS exhibit smaller ROIsoc, e.g. 15,000 to 0.7 million percent for FreeCAD.

For FOSH the ROIsoc is more closely tied to the value of the product. Where, for example, the open source syringe pump for medical use has a ROIsoc from 0.4 million to 6 million percent, while the designs for a bottle opener, which would be far more often used, have a ROIsocs range from 90 to 1,290 percent. A 3-D printable glide cam, has an economic value and likelihood of use between the two and thus has an ROIsoc in between as well ranging from 3,000 to over 100,000 percent. These calculations are theoretical and likely underestimated, but it is clear that open source development brings great value to society. The implication of those number needs to be further analyzed. With existing data, however, absorbing those open source designers is more likely to have a positive impact on the receiving countries. With more attentions provided to the field of open source, more people will engage in the similar activities creating a positive feedback loop. Thus, as more work is shared freely it will provide a benefit to whomever is willing to utilize those open source products and then further feedback is provided into the mutually beneficial system. Again this would indicate a conservative ROI for any given project.

4.2 Alternative Methods of Calculating Value

There have been some attempts to calculate value of large collaboration projects and the value of individuals that contribute to them. The Linux Foundation, estimated the value of Linux to be about $5 billion using source line of code (SLOC) and the constructive cost model (COCOMO) (2015). SLOC is used to calculate the actual number of lines of functioning code in a project and estimate the effort needed to produce this many lines. SLOC may result in an underestimation as commenting code is not counted, which is essential since readability is as important. Likewise the COCOMO model analyzes the number of lines of code to estimate cost and effort of a project. Kemerer discussed these two models and additional estimating methods (Function Points*, and* ESTIMACS), and suggested that the model predicted a better value when it is calibrated and the project is large

(1978). According to OpenHub, the Linux Kernel with more than 20 million lines of code evaluated by the COCOMO model, assuming 7,000 people are being paid $55,000 yearly, the estimated cost will be more than $300 million (2021, OpenHub). Robles et al. stated that to better measure efforts committed in a software project, it is important to identify who can be considered as full-time contributor as most of the work are performed by only a small portion of the participants (2014). With that, Roble et al. believed since the majority of the work is done by those considered to be full-time workers, the effect of other participants could be eliminated (2014). This approach is clearly not acceptable for the purposes of this study as by definition the majority of people that need this new method of value calculation would not be employed on it full time. At the same time all of these models, which are based on the market value of labor to create a product, severely under count the value that is created when the design is distributed in the open source context.

Download substitution value is thus superior for determining real value and should also be considered to calibrate these estimating models in future work. The other equations cannot be used due to lack of statistics provided from chosen FOSS. Even the lines of code added will be controversial on how accurately it reflects a single developer's true effort. As each line has different length and purposes. Other factors could be considered to improve the accuracy, however, the exclusion of other factors will not invalidate the value that should be credited to those top contributors. Since the assumption made for each downloaded software to be used only one month, this actually significantly reduced the actual impact of the software as well as their developers. Furthermore, the download statistics reflected on SourceForge is clearly not capturing all the potential users. Anyone with access to the internet could directly download the files for installation from designated repository without being counted into the download statistics. For institutions like universities or some firms, where they can distribute one software through virtual connection to every in-network devices, the usage through these connections is probably not reflected in download statistics either. At the same time, the downloads were treated as if they were all for a target country despite them being global. All of these factors increase the potential variability of the value and should be further refined in future work.

GitHub's repositories also show the work frequency of contributors, which could be quantified and integrated in to a more refined equation. IBM and Sensorica's models could be integrated if possible to better grasp the value that should be credited to each single contributor. Past contribution is also tracked in each user's GitHub file, that could be used for a multiplier into their future contribution depending on the quality of their past work, which is similar to Sensorica's reputation factor. In the study cases done above however, since it is explained the output is an extreme underestimation due to lack of download statistics and time period of the usage of the software, a more accurate equation should only result in a higher output of those contributor's effort even if pro-rating for downloads from a particular target country.

Sensorica's model is more sophisticated than the simple valuation estimation models presented here. The idea behind the Sensorica model is to enable anyone with skills to join and make a living with the distributed revenue without other financial support. Their model contains a bonus for each individual variable to benefit the contributors that work more regularly and correctly. They may face problems when contributor exchange credits to physical cash. However, this does explain the potential aggressiveness in their formula that tends to encourage an open source contributor to a work more regularly. Their model could be beneficial in terms of progressing the project and encourage OS workers to put in more effort, however, it might also underestimate a value that could be credited to a contributor that does not contribute as frequent as others. This may not necessarily be the disadvantage of the model, but taking in factors like frequency of work, quality of past work, and reputation means more effort to track each individual's progress. This placs extra burden on administration and on OS workers. Nevertheless, since Sensorica do pay their contributors once revenue is generated, their model does have a starting point.

The methods presented here are simple and easy to implement. The required inputs to compute the value credited to individuals are easy to obtain and quantify. The error, however, will be larger compared to a relatively more sophisticated system like Sensorica's model (2021). The models introduced here will produce rough estimation instead of an accurate measurement of one's effort; however, unlike Sensorica, the result here is not get exchanged for cash but rather access and mobility. It is used to reflect how much impact users created through their OS contributions. This credential would give countries or institution information of those credited individual, and if the cost of granting certain privileges is comparably lower than the potential estimated impact they have already created, it will be a net gain for both privilege granter and the contributors.

4.3 Implications

For FOSH, there are many other designs available on YouMagine and similar open hardware repositories that are even more popular. In this study objects with utility were analyzed, but there are many millions of other designs in toys, decorations etc. In addition, complex designs like 3-D printers themselves were not considered because of the complications of non-open hardware components like stepper motors. It should be pointed out that these designs are representative, although there are many other such digitally copied open hardware that would yield a higher value and ROIsoc compared to the designs chosen for the case studies. The results show the FOSH in general have a relatively lower value compared to FOSS, which has a marginal cost of zero, while manufacturing FOSH still requires the purchase of materials.

There are many other OS projects that are likely to have a greater economic impact as well. For example in FOSH, Arduino is an open source electronics platform that allows users to modify and upload their own design on their website (Arduino, 2021). Arduino's net sale in 2020 was estimated to be $180.5 million (ecommerceDB, 2021). As many of those Arduino microcontrollers could be used to offset much higher cost items (e.g. the syringe pump used as an example above was remixed to work with an Arduino rather than a Raspberry Pi (Lynch, 2015)). Similarly, the Open Source Computer Vision Library (OpenCV), a FOSS-based computer vision and machine learning software library, is extensively used by not only individuals, but also established companies and start-ups (OpenCV, 2021). OpenCV has download statistics on SourceForge of 22,572,880 times from 2001 to 2021 (SourceForge, 2021e).

A study on Linux Kernel from 2005 to 2011 and Ohloh projects has found about 50% of the contribution are considered to be performed by paid developers (Riehle et al., 2014). With the expansion of open source and the realization of the significance of open source projects, the number of paid-workers on OS will likely increase in the future. Though started in software, the adaptation of OS could be applied in any other fields. In this paper, the value of typical OS work by HQP has been proven to be a net gain for the economy of the destination country for allowing them mobility and even for the sending country if the HQP goes back or maintains his/her connections. Skilled immigrants are one of the biggest contributing forces for the development of the economy and science (Schultz, 1961;1963; Jones, 1971;

Blundell, et al., 1999; Psacharopoulos, 1981;1985;1994), however, the problem of limited mobility of those skilled people persists. The mechanisms introduced in this study could serve as an ideal tool to credit the contribution of the HQPs and grant them certain privileges (i.e. permit to work in another country, or even citizenship of a country). The cost to give those privileges compared to the anticipated ROI from the OS design case studies is shown to be minimal. In the long run the tax they pay converges with a native, so even with dependents they do not represent a burden for the local economy (Simon, 1984).

Many HQPs may face difficulties during the processing phase when they seek better opportunities in a country with more advanced economy. These include the price for visa processing, or the lack of information on the criteria on the application. If the receiving country could realize accepting HQP with documented OS value is a net gain for them, and start adopting necessary suitable policies on granting the free flow on targeted grounds, this could not only leverage the flow of HQPs that have the intention to move between countries, it also brings up the possibilities of more connection between developing and developed countries. Such connections could serve as bridge for knowledge flow to benefit back the sending countries and fill in the potential loss to the sending countries that have a HQP outflow.

The OS value mechanisms discussed here is a small initiation of the idea that borders between countries could be more open, especially for highly qualified personnel. Certainly this mechanism does not only have to function for the HQPs with the desire to seek a better job at a different location, it could also provide credentials for people anywhere that are already contributing to open source. The credit is reflected by the matching values they have generated from the usage of their OS projects by people all over the world. If a more mature and accurate evaluation system were created, this credit or value could be treated as a digital currency that the contributor can utilize as a waiver to exchange certain goods or services. This could help some HQPs with monetary concerns not only be more mobile across countries as focused on here, but also provide the basis for making more resilient economies. With the recognition of the contribution by those OS developers, more people may be motivated to contribute to the society for everyone's benefit. From the handful of case studies above, estimated value generation is in the millions of dollars as their lower bound, which is a known significantly underestimated value. With more people participating in OS development, not only would a substantial value be created but software and hardware technologies could also be advanced.

Many OS contributors are are already financially compensated from industries that support OS development (Riehle et al., 2014). It is clear from the results presented here that society is gaining from those free licensed software or hardware as their cost is relatively low or minimal compared to a commercial equivalents. The impact of such phenomenon is challenging to quantify accurately, but the conservative underestimates shown here indicate that any investment in OS development provides enormous returns. With such mechanism to leverage the mobility of highly qualified personnel by providing recognized credentials, at the same time attracting more skilled workers into the OS field, the actual impact could be much greater than the calculations shown here for society.

It is clear that FOSS and FOSH generate significant savings for users. Though estimating the value represented by those OS projects using the price of an equivalent commercial product has some limitations. For example, the purchase of a commercial product usually comes with some form of warranty and customer support, the cost of providing those services is included in the retail price of those products. For DIY manufacturing or downloading, warranties are generally not available unless the OS product is sold by a company. Similarly, although there are often users providing support for new users by uploading instruction videos and replying questions on a forum in open source products, customer support can not be relied upon unless the OS product is commercialized. Despite the limitations, the rough estimation result from this system is still valid in term of crediting those OS developers with greater mobility. If a proper incentive is provided to the public to work on more FOSS or FOSH, the potential value is incredible. It is possible the mass adoption of FOSS could unbalance its business equivalent, said by Brydon and Vining, however, many mainstream firms participate in FOSS to further polish their commercial product, who at the same time subsidize the FOSS core they used from the revenue created (2008). It is also believed the gain for firms participating in FOSS overcome the loss they face sharing their code to other competitors (Brydon & Vining, 2008). Companies that learn to navigate the OS business world appear to be those positioned to profit in the future.

Mechanisms to use OS to increase HQP would tend to open borders. Bauder found that with an open border a large flow of immigration from developing countries to developed countries will not create a significant population diaspora (Bauder, 2003). It is generally seen that people from Organization for Economic Cooperation and Development (OECD) countries have fewer restrictions on their mobility traveling abroad than other countries (Neumayer, 2006). This is also supported by research conducted by Mau et al. that showed some non-OECD countries in Asia or Africa were losing accesses to other countries (2015). For developing countries, a certain flow of emigration could potentially encourage individuals from that country to pursue higher education (Lindsay & Allan, 2002). In this way, "brain drain" could be replaced by "brain circulation" and help skilled workers' sending countries (Lindsay & Allan, 2002). An increase of more than $10,000 in welfare is also found by a randomly selected foreign worker from a less developed country (Kennan, 2013).

From the perspective of basic human rights, one's opinion on where he/she wants to relocate should be valued or considered by the receiving country. Although a large flow of immigrants can cause a brain drain for the sending country in a short run (Saxenian, 2005), the mobility of those potential immigrants are limited, and this limitation can cause them to immigrate permanently (Pécoud & Guchteneire, 2006) instead of changing the brain drain to a brain circulation. That is a reason favoring more open borders, not only for the sake of absorbing more skilled workers, but also aid those sending countries from not losing their documented and undocumented HQP permanently. For example, Egypt saved three quarters of a million dollars in 2000 by making the border more open and its custom process easier (Neumayer, 2006). From above, if a country could gain more skilled workers while saving money on admitting them inside its border, it is certainly a win-win for the receiving country and those HQPs. Without a restrictive border control, skilled workers have a higher chance of going back their own countries and improving development. Overall, the flow or circulation of skilled workers at an international level is seen to be a net gain for the globe as a whole. If a healthy circle lasts, the disparities of development between countries could be reduced as well.

Potential costs due to the brain drain effect was discussed previously; if free movement of the HQPs is achieved, some may return to their home countries instead of permanently staying in the destination countries and create brain circulation to compensate the initial brain drain when they left their home countries (Lindsay & Allan, 2002). Brain circulation was discussed by Saxenian (2005) that as foreign-educated returnees serve as a key bridge to connect firms in Silicon Valley and their home countries, it stimulates the emergence of local start-ups and multinational cooperation. In the long term, such entrepreneurship build relations with local policymakers and transfer the advanced model from Silicon Valley to their home countries, which further creates an incentive for foreign graduates in US to seek opportunities back at their home countries. Silicon Valley has embraced OS as it now is the foundation for most if not all Internet-based companies, and by applying incentives for HQP to assist in OS this can enable greater HQP mobility following the success of a successful brain circulation also championed by Silicon Valley as well.

5. Conclusion

This study evaluated methods that could be used to quantify OS value creation from documented and undocumented HQP for the benefit of the international community by enabling a means of both skill verification as well as enabling HQP a means to earn access without credentials or substantial financial resources. The system introduced here focuses on the mobility of highly skilled worker, which will carry a net gain to the destination country. The current infrastructure used for admitting immigrants into the US is inadequate. Not only does that personnel have to have the financial ability to process required paper work and validation, they are also examined by their level of education or their capital. The system discussed here quantifies the value produced by OS developers in different environments and credits them the value their work represents by providing three mechanisms to fund HQP mobility.

The case studies overwhelmingly showed that example OS developers produced far more value than the cost to enable their mobility. Thus the societal return on investment for granting mobility to documented OS developers is astronomical. Even using an overly underestimated method described in this study, the results of this work clearly show that OS developers can create enough value that if they want to immigrate, accepting such OS HQP is a net gain for the destination country from an economic standpoint. Potential brain drain does exist, but if the flow of mobility rules are free enough, they will not tend to stay permanently in the destination country, thus producing a brain circulation when they go back to their home country. Finally, future research is needed to improve the methods developed here to accurately calculate the value represented by OS developers. OS projects should also implement a better infrastructure to record all activities committed by their developers, and derive necessary factors into the consideration of a more refined and accurate estimates of value and ROI.

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