A Additional Proofs and Results on IFP

Given the generic IFP model, we study different settings where we have different constraints on consumption. We assume that there is a basic needs (minimum subsistence consumption) value that provides a lower bound on consumption leading to the inequality constraint in IFP model by setting $b_t \leq c_t \leq a_t$ for all t, where b_t is a known basic needs parameter. Note that the basic needs we discuss are different from the mainstream optimal consumption paths: previous work always assumes that there are enough assets available at all times to cover basic expenditure (thus the individual would never go bankrupt) [11]. But in our setting, we consider a realistic scenario that due to uncertainty, the individual cannot always act ultimately rationally and have enough assets to cover their minimum subsistence, and hence, the amount of assets could drop to a value below the basic needs.

The constraints (e.g., minimum subsistence) we introduce play a vital role in the consumption behavior of an individual. For instance, in the IFP model, an agent that is maximizing utility can avoid ruin assuming they have any realistic constraint such as minimum subsistence. This is formalized in our Lemma 1.

Lemma 1. *Assuming the income y_t ($y_t \geq 0$) is drawn from a distribution with known mean (denoted by y), if we allow the agent to manage their consumption without any restrictive constraints other than $0 \leq c_t \leq x_t$, then under the CRRA utility with $\gamma_c = \frac{1}{2}$ the agent always prefers consuming with infinite horizon over going to ruin early. If on the other hand we require the minimum subsistence constraint $b_t \leq c_t$ together with the IFP constraint $c_t \leq x_t$, then there are instances with no feasible solution even if agents might possess sufficient assets $x_t + y_t$*

The proof of Lemma 1 is as follows,

Proof. Assume you are given parameter β and utility $u(c) = 2 \cdot c^{1/2}$ ($u(c) = \frac{c^{1-\gamma_c}}{1-\gamma_c}$ with $\gamma_c = \frac{1}{2}$). Also, assume $r = 1$ for the current model.

Consider the optimal consumption sequence that you get where the agent goes to ruin at time point T (here, asset ruin is assumed to be the point where the available assets for the next iteration reach 0). Let this be $C = \{\widehat{c}_1, \widehat{c}_2, \dots, \widehat{c}_T\}$. Note that going to ruin at time T is possible only if $y_{T+1} = 0$ (since $\widehat{c}_T \leq a_T$ and $a_{T+1} \geq y_{T+1}$ and therefore if $Y_{T+1} > 0$ then $a_{T+1} > 0$).

Let ϵ be such that $\widehat{c}_T \geq \epsilon \frac{(1+\beta^2)^2}{4\beta^2}$ (Note that $\frac{(1+\beta^2)^2}{4\beta^2} \geq 1$ for all $\beta > 0$ since this translates to $(\beta^2 - 1)^2 \geq 0$). Consider the amended sequence where $C^* = \{\widehat{c}_1, \widehat{c}_2, \dots, \widehat{c}_T - \epsilon, \epsilon, \dots\}$. We can see that with this consumption sequence, the agent does not go to asset ruin at point T since we consume less than $\widehat{c}_T$ and we still have ϵ left.

Let $U = \sum_{t=1}^{T-1} \beta^t \cdot 2 \cdot \widehat{c}_t^{1/2}$. Let the total utility from sequence C be $F(C)$ and the total utility from sequence C^* be $F(C^*)$. We can see that $F(C) = U + \beta^T \cdot 2 \cdot \widehat{c}_T^{1/2}$ and $F(C^*) \geq U + \beta^T \cdot 2 \cdot (\widehat{c}_T - \epsilon)^{1/2} + \beta^{T+1} \cdot 2 \cdot (\epsilon)^{1/2}$.

Given our ϵ, we can see that,

$$\begin{aligned}
&\widehat{c}_T \geq \epsilon \frac{(1+\beta^2)^2}{4\beta^2} \\
&\implies \widehat{c}_T - \epsilon \geq \epsilon \frac{(1-\beta^2)^2}{4\beta^2} \\
&\implies (\widehat{c}_T - \epsilon)^{1/2} \geq \epsilon^{1/2} \frac{(1-\beta^2)}{2\beta} \\
&\implies \widehat{c}_T - \epsilon + 2\beta\epsilon^{1/2}(\widehat{c}_T - \epsilon)^{1/2} + \beta^2\epsilon \geq \widehat{c}_T \\
&\implies (\widehat{c}_T - \epsilon)^{1/2} + \beta \cdot \epsilon^{1/2} \geq \widehat{c}_T^{1/2}
\end{aligned}$$

which implies that $F(C^*) \geq F(C)$ and therefore, C^* is a better consumption sequence. This contradicts our earlier assumption that C is the optimal consumption sequence.

While we have only shown this for a specific choice of γ_c, it should be possible to see similar but more complicated arguments that would work for any concave utility function since they fundamentally behave the same way. Now we can see that the agent can always avoid ruin and optimize utility if allowed variability in consumption (without realistic elements).

That is, in the proof of Lemma 1 the agents are allowed to consume almost nothing (the proof of Lemma 1 works if we allow the agent to consume infinitesimally small amounts). But in real-world scenarios this is unrealistic. Therefore, we add a lower bound for basic needs when considering consumption in the following proposition. We can see that this could lead to early ruin with IFP.

Proposition 1. *Assume we have minimum subsistence constraints, $b_t \leq c_t$ where b_t is the minimum subsistence at time t, as well as an upper bound on the consumption introduced by IFP [7], $c_t \leq x_t$ (also assume return on saving, r is 1). Assume the model behaves under the equation, $x_{t+1} = x_t + y_t - c_t$. Under these constraints, there are instances where the individuals would have no feasible solutions with IFP that could account for minimum subsistence even though the individual might be able to account for it by spending the current income, y_t.*

We will argue the validity of this claim, as follows,

Proof. Consider the case where $x_t < b_t$ for some t. We can clearly see that the constraint $b_t \leq c_t \leq x_t$ can no longer be satisfied so there is no valid solution at that point. Since IFP does not allow borrowing, the agent cannot survive with minimum subsistence. Note that this is true even if $(x_t - b_t) + y_t > 0$. This implies that even though we could have accounted for the lack of assets by borrowing from the available income, the constraints on IFP do not allow this course of action and the agent fails to provide for the required minimum subsistence. This implies that the IFP model would not have an admissible solution and therefore IFP fails at this point. This provides us with the desired result.

In summary, under the IFP model, the agent can only consume from the assets and cannot use income, and it could force the agent into situations where they cannot satisfy the consumption constraints which they might have been able to fulfill if they were allowed to use their income.

B Detailed Argument on the Model from §3.2

In this section, we will analyze how we introduce ruin to IFP and how it leads to our model, as well as the technical details involved in introducing the minimum subsistence constraints to the new model in §3.2.

For the rest of the section, we will mainly use the following notations. We will use t for time and x_t, y_t, b_t, c_t for the assets, income, minimum subsistence, and consumption at time t respectively. We define τ_0 be the time to ruin, i.e. $\tau_0 = \inf\{t \mid a_t \leq 0\}$. Also, we define τ_d to be the time of death where τ_d comes from an exponential distribution with parameter γ. We let $u(c)$ be the utility (where u is a concave function) achieved by the consumption value c (we will also assume $u(0) = 0$) and β be the discounted factor in the discounted utility model.

Adding Ruin Constraints to IFP

In this section, we will introduce the ruin constraints to IFP and derive a modified model that we will use thereafter. Let c_t, x_t and y_t be the consumption, assets and income at time t. Let r be the return on assets. We will first modify the IFP to include ruin, minimum subsistence and time of death. Introducing time of death, idea of ruin, and minimum subsistence to IFP gives us the following,

$$\max E\left(\sum_{t=1}^{\min(\tau_d,\tau_0)} \beta^t u(c_t)\right)$$
$$s.t.\ x_{t+1} = r(x_t - c_t) + y_t$$
$$b_t \leq c_t \leq x_t$$

Given that the optimization now terminates at the time of ruin, we need to add some constraints that would allow the agent to control their consumption such that they have an opportunity to avoid ruin. To do this, we will use the same constraint used by [2]. Their work introduces a soft constraint $\mathcal{P}[\tau_0 \leq \tau_d] \leq \phi(x_0)$ where $\phi(x_0)$ is a probability parameter that depends on the initial assets. Note that given this ruin constraint, we can remove the upper bound on c_t since the ruin constraint would prevent the individuals from borrowing without bounds (the task which the upper bound is meant to do)

This gives us,

$$\begin{aligned}
&\max E\left(\sum_{t=1}^{\min(\tau_d,\tau_0)} \beta^{t-1}u(c_t)\right)\\
&s.t.\ x_{t+1} = r(x_t - c_t) + y_t\\
&\quad b_t \le c_t\\
&\quad \mathcal{P}[\tau_0 \le \tau_d] \le \phi(x_0)
\end{aligned}$$

and the continuous relaxation of this leads to,

$$\begin{aligned}
&\max E\left(\int_0^{\min(\tau_d,\tau_0)} \beta^t u(c_t)dt\right)\\
&s.t.\ dx_t = ((r-1)x_t - rc_t + y_t)dt\\
&\quad b_t \le c_t\\
&\quad \mathcal{P}[\tau_0 \le \tau_d] \le \phi(x_0)
\end{aligned}$$

As we have seen in §3.2, we can see that this can be written as,

$$\max E\left(\int_0^{\tau_0} e^{-\gamma t}\beta^t u(c_t)dt + Pe^{-\gamma\tau_0}\beta^{\tau_0}\right) \tag{7}$$

$$s.t.\ dx_t = ((r-1)x_t - rc_t + y_t)dt \tag{8}$$

$$b_t \le c_t \tag{9}$$

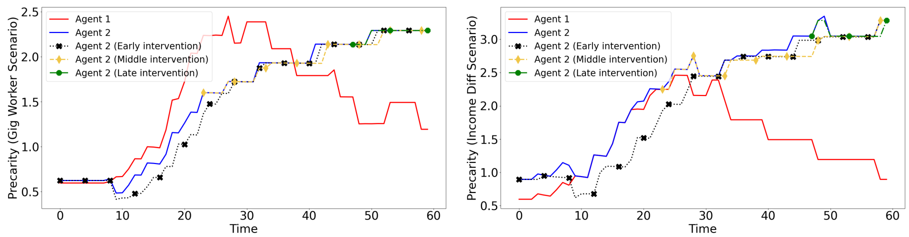
where P is a Lagrange parameter and $E\left(e^{-\gamma\tau_0}\beta^{\tau_0}\right)$ is the same as $\mathcal{P}[\tau_0 \le \tau_d] \le \phi(x_0)$.

Given that we have a proper formulation, the next step we take is to work out a solution for this. We first start off with the equation (7), for which we provide a detailed analysis on how to solve and how we can derive an optimal consumption value given the the equation (7), in §3.2. Next, we provide details on how we can add minimum subsistence using a Lagrange parameter and what this implies for the solution.

Additional Details on §3.2 and Adding Minimum Subsistence

In this section, we will mainly provide some additional details on the value function we derived such as how we derive k_1, and then show the modifications we would have when we add minimum subsistence constraints. In §3.2, we have shown how we can derive a value function V for the problem and how we can solve this to get a polynomial that involves $c(x_t)$,

$$x_t = k_1 c(x_t)^{\frac{\gamma_c r}{r-1-\frac{\beta}{2}}} + \frac{\gamma_c r}{\frac{\beta}{2} + (\gamma_c - 1)(r-1)} \cdot c(x_t) - \frac{y_t}{r}$$



(a) (b)

Fig. 4. 12-month tax interventions for the same two scenarios studied in §4.2. The gig vs. office worker scenario has agents starting with different latent initial instability, similar initial assets, and similar starting income distributions. The colors red and blue correspond to agents 1 and 2, respectively. The minor income difference scenario starts with different initial instability and initial assets ($43,800) with marginally different initial incomes. Agent 1 (red line) has an income of $3,930 and Agent 2 (blue line) has an income of $3,910. The lines with markers in black, yellow, and green represent early, middle, and late intervention start points, respectively.

and we can see that the solution to the derived equation satisfies maximization of the value function (since it was derived as a solution to the value function),

$$\beta V(x) = u(c(x)) + \frac{((r-1)x - rc(x) + y)}{r} u'(c(x)) \tag{10}$$

For any fixed set of values of γ_c, β, r, finding $c(x_t)$ boils down to solving a polynomial of some specific degree. As we have states before in §3.2, given $V(0) = P$, we can also see that,

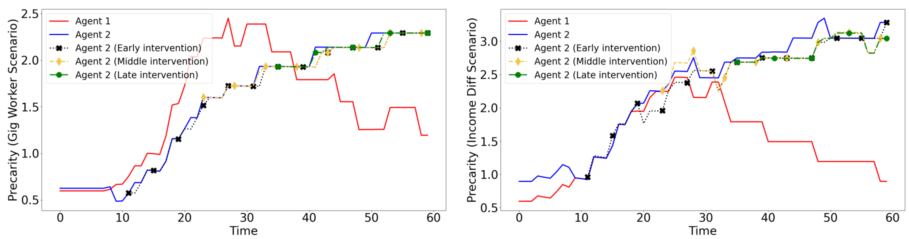
$$\begin{aligned} \beta P = \beta V(0) &= u(c_0) + \frac{(y_0 - rc_0)}{r} u'(c_0) \\ &= \frac{c_0^{1-\gamma_c}}{1-\gamma_c} + \frac{y_0}{r} c_0^{-\gamma_c} - c_0^{1-\gamma_c} \\ &= \frac{\gamma_c}{1-\gamma_c} c_0^{1-\gamma_c} + \frac{y_0}{r} c_0^{-\gamma_c} \end{aligned}$$

where c_0 is the consumption when $x = 0$ and y_0 is the income at that point (note that since we assume the income process stops at this point in our setting, we can assume y_0 to be 0).

Note that, given c_0, and when $\beta/2 \gg r - 1$, we get,

$$0 = k_1 + \frac{\gamma_c r}{\frac{\beta}{2} + (\gamma_c - 1)(r-1)} \cdot c_0^{1 + \frac{\gamma_c r}{\frac{\beta}{2} - (r-1)}}$$

which gives us the desired k_1.



(a) (b)

Fig. 5. Stimulus interventions for the same two scenarios studied in §4.2. The gig vs. office worker scenario has agents starting with different latent initial instability, similar initial assets, and similar starting income distributions. The colors red and blue correspond to agents 1 and 2, respectively. The minor income difference scenario starts with different initial instability and initial assets ($43,800) with marginally different initial incomes. Agent 1 (red line) has an income of $3,930 and Agent 2 (blue line) has an income of $3,910. The lines with markers in black, yellow, and green represent early, middle, and late intervention start points, respectively.

Minimum Subsistence. In this section, we will try to introduce the minimum subsistence constraint on top of the value function we derived previously. Let x be the assets, $c(x)$ be a function that gives consumption value given x and b be the minimum subsistence value. Note that, given equation 10 introducing the consumption constraints can be done as follows,

$$\begin{aligned} \max \beta V(x) &= u(c(x)) + \frac{((r-1)x - rc(x) + y)}{r} u'(c(x)) \\ \text{s.t. } c(x) &\geq b \end{aligned}$$

via a modification involving the Lagrange multipliers over the constraints. With this, we get a modified value function $\widehat{V}(x)$ (with Lagrange multiplier λ).

$$\begin{aligned} \beta \widehat{V}(x) &= \beta V(x) + \lambda(b - c(x)) \\ &= u(c(x)) + \frac{((r-1)x - rc(x) + y)}{r} u'(c(x)) \\ &+ \lambda\,(b - c(x)) \end{aligned}$$

In order to analyze the behavior of this function, we can KKT conditions. With KKT conditions, we get the following. We can see that complementary slackness gives us,

$$\lambda(b - c(x)) = 0$$

Also from the constraint itself, we get $c(x) \geq b$.

Using the stationary conditions we also get,

$$\frac{\partial \beta \widehat{V}(x)}{\partial x} = 0$$
$$\implies$$
$$u'(c(x))c'(x) + \frac{((r-1) - rc'(x))}{r} u'(c(x)) + \frac{((r-1)x - rc(x) + y)}{r} u''(c(x))c'(x) - \lambda c'(x) = 0$$

which gives us,

$$\lambda = \frac{((r-1)x - rc(x) + y)}{r} u''(c(x)) + \frac{r-1}{r}\frac{u'(c(x))}{c'(x)}$$

Along with complementary slackness, we can see that this implies,

$$\left[\frac{((r-1)x - rc(x) + y)}{r} u''(c(x)) + \frac{r-1}{r}\frac{u'(c(x))}{c'(x)}\right](b - c(x)) = 0$$

which is a well defined differential equation given b. Given this differential equation, we can see that we can still use analytical methods on top of this and find solutions to $c(x)$ given any fixed b. Let c_1 be the solution to $x = k_1 c(x)^{\gamma_c} + \frac{\gamma_c r c(x)}{(\gamma_c - 1)(r-1)} - \frac{y}{r-1}$. In this setting, we can see that we get the consumption,

$$c(x) = \max\{c_1, b\}$$

These functions were calculated using the WolframAlpha[4] symbolic engine. We can see that this gives us an approach to find the $c(x)$ value and therefore a way to define a consumption sequence.

C The Simulation Framework: Putting it all together

In this section, we provide a detailed explanation on the assembly of the simulation framework.

Experimental Environment. The experiments in this paper were carried out using a Google Colab environment. The language used is Python and the experimental suite only relies on generic libraries such as SciPy, NumPy, and Matplotlib.[5] The code and all the other needed source codes for importing necessary dependencies are included in the supplementary material.

Agents. Agents in the framework are individuals who earn income, possess assets, and decide whether to consume or save. We form an income distribution of 10,000 agents using 2019 income data of the US Census Bureau's Annual ASEC

[4] https://www.wolframalpha.com/

[5] `https://scipy.org/` `https://numpy.org/` `https://matplotlib.org/`

survey of the Consumer Price Index – reported by the IPUMS Consumer Price Survey [5, 10]. We also assign each individual a net-worth value, i.e., assets minus initial liabilities. The net worth is assigned using detailed median percentile net worth data and median net worth by income by percentile data from the Federal Reserve [3]. The minimum subsistence values (charges for basic needs such as food and shelter) are based on mean annual expenditures in 2019 from the Consumer Expenditure Surveys of the US Bureau Of Labor Statistics [12]. Agents attempt to maximize their utility in the face of an uncertain future using the approach described in the previous section. We fix the asset appreciation rate $r = 1.10$.

Shocks. A shock is a change to an agent's finances (i.e., observable economic features which are income and assets). Shocks can affect their decisions on how to consume and save. In this paper, we consider shocks that affect income either positively or negatively. We include two variants of real-world income shocks: *permanent* shocks and *temporary* shocks. Permanent shocks are changes to income that last until the next permanent change (e.g., unemployment, promotions, and demotions). Temporary shocks are changes that only affect the income at a specific point of time (e.g., a one-time pay cut/bonus, reduction of work hours, or economic impact payment) and do not have a lasting effect on income [6].

Algorithmic Decision Making. In our experiments, we use a classifier that makes "decisions" about an agent, yielding a shock (positive or negative). Given a shock value w, if the agent gets a positive outcome from the classifier, income is changed by a multiplicative factor of $1+w$ and if the agent gets a negative outcome from the classifier, income is changed by a multiplicative factor of $1-w$. We use a shock value of 0.4 for permanent shocks and a shock value of 0.6 for temporary shocks. The choice of 0.4 for permanent shock size is due to the ratio between the average income of two consecutive groups being around 1.4 and the choice of 0.6 for temporary shock size was to ensure that there was a clear difference between the two types of shocks. For temporary shocks, the change to the income lasts for a single time step, while for permanent shocks, the income is changed permanently until another permanent shock happens. In our experiments, we use a classifier that is trained to predict an agent's "financial well-being" based on their income and assets. Well-being is a subjective self-reported score (based on extensive interviews) by the Federal Reserve that accounts for how people think are doing financially (if they are “doing at least okay financially" or not) [4]. We construct a training set by assigning a label of 1 to an agent based on the probability of an individual reporting that they are financially stable (derived from the well-being score). The classifier that we use is a gradient-boosted binary.

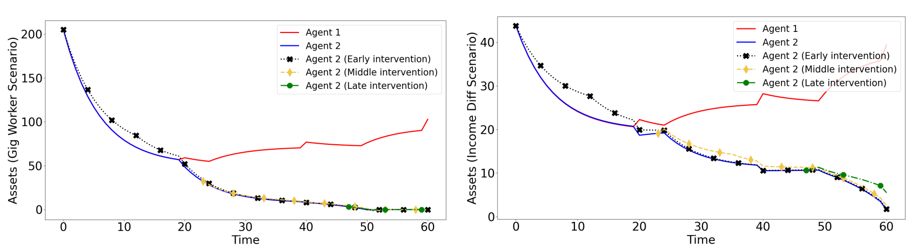
More Details on the Precarity Index. In this paper, we encode agent trajectories as a sequence of asset distribution deciles. We set the initial instability of an agent to be a function of the number of transitions required to reach the highest asset decile from their current decile and their perceived well-being (as defined in the paragraph above), as follows. We scale the transition-based difference by the inverse of the perceived well-being to have a more comprehensive initial instability based on both actual monetary values and the perceived self-reported economic well-being of people. Formally, for each agent, given their transition-based difference $\Delta(s_1) = 1 + s_{\max} - s_1$ (where $s_{\max}$ is the best possible state and s_1 is the current state), and a well-being value ξ (in the range of 0 to 1), we set the initial instability to be $r(s_1) = \frac{\Delta(s_1)}{\xi}$.

As observed by [8], the precarity measure becomes less sensitive to any change as the length of the trajectory increases. This is because of the potential decrease in the relative number of transitions as a fraction of sequence length as well as a reduction in the variability of the visited states over time. In this paper, we mitigate this concern by evaluating precarity over a (sliding) window (of size 10); this provides a sufficiently long enough history of events to compute precarity at each time point.

D After-intervention Precarity and Assets

In this section, we give a graphical representation of the precarity and assets post-interventions. Figure 6 is a pictorial example of assets for the 12-month tax intervention for one pair – **the exact same pair** studied in §4.2. Similarly, Figure 7 is a pictorial example of the results for the $3,000 direct subsidy for one pair – **the exact same pair** in §4.2. In both cases, interventions help them both temporally and financially in terms of durability.

The post-intervention precarity plots follow the same pattern as the corresponding asset plots in §5. That is, with financial help (tax breaks or stimuli) the agents become less precarious. The more impactful interventions, i.e., earlier and more persistent interventions help the agents become less precarious more prominently than smaller interventions. The results are shown in Figures 4 and 5 for both the scenarios studied in §4.2 and the corresponding interventions in §5.



(a) (b)

Fig. 6. Assets with 12-month tax breaks for the exact same pair per scenario in §4.2, Figures 2 and 3. Here, "gig worker" is the left and "income difference" is the right figure. Markers in black, yellow, and green depict early, middle, and late interventions.

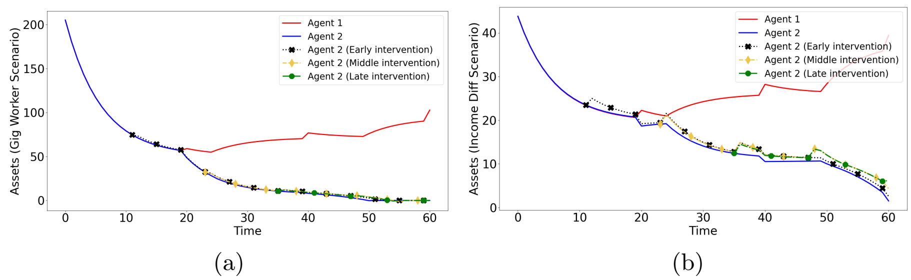


Fig. 7. Assets with subsidies (of $3,000) for the exact same pair per scenario in §4.2, Figures 2 and 3. Here, "gig worker" is the left and "income difference" is the right figure. Markers in black, yellow, and green depict early, middle, and late interventions.

E Direct Subsidies

In this section, we provide detailed analysis of our experiments using direct subsidies. Direct subsidies, also known as stimulus checks, are direct payments to help people in financial need. In this setting, as before, our goal is to examine the three factors of the start time of the intervention, resulting durability, and dependence on the intervention amount.

We explore two values of subsidies in the amounts of $3,000 and $600 (similar to the smallest subsidy out of three COVID-19 installments during the two years of the pandemic peak in 2020-2021) with different start points for 50 pairs of agents in each of the "minor income difference" and "gig vs. office worker" scenarios examined for the tax incentives in §5. Similar to §5, we experiment with interventions that are *early* (3 subsidy installments every 12 months starting at timepoint 12), *middle* (3 payments every 12 months starting at timepoint 24), or *late* (3 payments every 12 months starting at timepoint 36), with two different subsidy amounts ($3,000 versus $600) in each intervention.

Analysis As with tax relief, subsidies work, as we can see in Table 2. Corresponding post-intervention precarity and asset plots for the same pairs studied

Table 2. Mean intervention durability for 50 pairs of agents in each scenario for early, middle, and late subsidies (studied separately with $3K and $0.6K paychecks). Assets are in thousands of dollars and rounded to the closest $1,000.

Scenario	Months			Assets		
	Early	Mid	Late	Early	Mid	Late
Gig Worker (3K)	**36.1**	25.3	12.9	**53**	45	25
Gig Worker (0.6K)	**29.4**	21.8	11.1	**12**	11	6
Income Diff (3K)	**46.1**	35.5	23.3	**47**	46	31
Income Diff (0.6K)	28.4	28.4	20.6	9	**10**	8

in the previous section are in Appendix D. The takeaways are similar to the tax incentives. That is, knowing the diverging latent precarious nature of agents beforehand (as early as possible) can help policy-makers, in the long run, both in terms of time and money. The same amount of funds allocated for a specific type of intervention could be optimally used if it is disbursed before a diverging point in observable features when agents are only latently precarious. Moreover, bigger stimulus checks help the agents amass more assets and stay afloat longer. We look at some real-world statistical corroborations as well in the following appendix section to confirm if the overall trends of our results match real-world statistics.

F Statistical Corroboration

The main goal of fiscal stimulus is to "maximize the near-term boost to economic growth without weakening the economy's longer-term prospects. This requires that the plan be implemented quickly; that its benefits go to those hurt most by the economy's problems; and that these benefits not damage longer-term fiscal conditions" [15, 14]. Our findings illustrate the effectiveness of early interventions when providing fiscal stimulus.

Published statistics after the CARES Act funds were disbursed show increased financial resilience to adverse shocks among lower-income households. [1]. This durability is reflected in our findings. In another statistic, payments provided under the Consolidated Appropriations Act (payments of $600 per eligible taxpayer) mostly disbursed in January 2021 resulted in personal savings increase from 13.5% in December 2020 to 20% in January 2021. This shows household wishes to save the money [9] which matches our results on saving patterns and asset accumulation after interventions.

In terms of economic stress and assets, economic stress negatively affects families' ability to save. Economic stress resulted in less than 40% chance of household savings (according to data from 2010 to 2016), while families with no such stress had more than a 50% chance of saving [13]. This matches the overall trend we observed in the two scenarios we examined where compounded adversity and latent volatility would result in fewer assets. We note that [8] also report on the effect of compounded shocks.

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