

Optimal Partial and Full Disability Insurance with an Application to Korea

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In this paper, I investigate the optimal disability insurance (DI) when partial and full disability are privately observed over the life cycle. I demonstrate that in the social optimum, partially disabled agents are induced to supply labor despite substantial government transfers unless labor supply is relatively elastic and their productivity is significantly reduced. I then apply the framework to quantitatively evaluate Korea's DI programs, which include partial and full disability benefits. In the calibrated model, I find that welfare gains from replacing Korea's DI programs with the corresponding optimal system amount to a 1.17% increase in consumption. Such a reform significantly raises the utility of both types of disabled agents at relatively small utility costs of able agents. Equity gains from this redistribution account for 73.4% of the total welfare gains, whereas efficiency gains from the optimal allocation account for 26.6%.

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I. Introduction

Disability insurance (DI) is an important component of social welfare because a disability can substantially reduce a person's earning capacity. DI is also one of the largest social welfare programs in many developed countries. In the U.S., for example, the Social Security Disability Insurance (SSDI) program provided nearly 11 million people with \$142 billion in benefits in 2014 (Social Security Administration, 2015). Given the fiscal significance of DI, work incentives for

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disabled agents have recently become one of the key policy goals in designing a DI program. In an ideal DI program, disabled agents with mild work limitations should be encouraged to participate in labor markets, but those with severe work limitations should be provided with generous benefits. The government should distinguish full and partial disability in benefits and other aspects of a DI program. In the literature on optimal DI, however, most papers focus only on DI programs for the fully disabled, ignoring the partially disabled and work incentives for them.¹

This paper contributes to the literature by providing a rigorous but tractable framework to evaluate DI systems that explicitly takes full disability and partial disability into consideration. Specifically, I develop a dynamic life-cycle model wherein the disability status, which can be *able*, *partially disabled*, or *fully disabled*, changes over the life cycle. I assume that partial disability and full disability are random shocks that reduce agents' labor productivity partly and completely, respectively. I also assume that the disability status is privately observed. These assumptions make this model structurally analogous to the standard dynamic Mirrlees models. The equity–efficiency trade-off that is central to DI programs and any other social insurance program can be analyzed with the developed model.

Using the model, I first characterize the theoretically optimal allocation. In particular, I shed light on the distinction in the allocation of consumption and labor between the partially and fully disabled, capitalizing the well-established results in dynamic Mirrlees economies. I then apply the framework to Korea to examine the economic effects of the country's various DI programs. Specifically, I quantify the welfare gains from the optimal reform, i.e., a policy change that replaces the current Korean DI system with the optimal one. I also decompose the welfare gains to explore their sources and draw policy implications for Korea's DI programs.

I choose Korea for the quantitative welfare analysis rather than another major country, such as the U.S., for two reasons. First, Korea has DI programs targeted at both full and partial disability. Drawing direct policy implications for specific DI programs from the quantitative analysis is easy. The same cannot be said for roughly half of the OECD countries, which do not have social welfare programs for partial disability (OECD, 2010). Second, the economic effects of Korea's DI programs have been rarely investigated quantitatively. To the best of my knowledge, this paper is the first that provides a comprehensive quantitative welfare analysis on the whole Korean DI system. Thus, this paper significantly contributes to the literature on Korea's DI system.

This paper presents several findings. First, inducing partially disabled agents to provide labor supply for as long as they can is generally optimal. However, they should not work too much because they are not as productive as able agents. For this reason, the optimal allocation exhibits high and positive marginal tax rates on

¹ A review of the related literature is provided later in this section.

their labor income in the calibrated model. Moreover, if their labor supply is sufficiently elastic, it can be optimal to induce them to retire early. Second, the government should continue to give partially disabled agents sufficient benefits under the optimal system because their earnings are insufficient to finance their consumption. In the calibrated model with baseline parameters, for example, an agent with lifetime partial disability finances 43.59% of his lifetime consumption with government transfer payments under the optimal system. These results suggest that in designing DI programs, the government should carefully balance work incentives and income support for the partially disabled.

Quantitatively, in the model with baseline parameters values, the optimal reform will yield significant welfare gains, which amount to a 1.17% increase in consumption for all agents. Such welfare gains can be attributed to either (i) the equity gain from the redistribution to provide better insurance against the disability risk or (ii) the efficiency gain from reducing unnecessary distortions in resource allocation under Korea's DI system. The decomposition analysis indicates that the equity gain accounts for 73.4% of the total welfare gains; the efficiency gain, only 26.6%. The optimal reform improves social welfare mainly through the redistribution from able agents to disabled ones to better protect them from the disability risk.

In the calibrated model, the utility gains from such redistribution can be enormous for disabled agents. For example, in the baseline model, the optimal reform raises the lifetime utility of an agent with a lifetime partial disability by 22.74% and that of an agent with a lifetime full disability by 50.86%. Such hikes in disabled agents' lifetime utility come at the expense of able agents who have to pay more taxes as a result of the optimal reform. Fortunately, the lifetime utility of a lifelong able agent falls by only 0.69%. This number is possible because the government can give more transfers to disabled agents, whose population share is quite small, by collecting slightly more taxes from the able, whose population share is very large.

The quantitative analysis in the baseline model also reveals the distortions under Korea's DI programs that account for the efficiency gain. First, able agents tend to work slightly less than they will in the social optimum due to high marginal labor income tax rates. Second, partially disabled agents often choose to retire early, due to low labor productivity in their 50s and 60s, unlike in the optimal allocation. Relatedly, such agents provide excessive labor supply when they are young to make up for the income loss caused by the early retirement. The optimal reform improves social welfare by reallocating labor supply across various types of agents to eliminate such inefficiency.

I then examine the robustness of the main findings by changing key parameter values or relaxing the assumption that disability is private information. Even in these models, the optimal reform can still improve social welfare significantly. In particular, if labor supply is more elastic, the welfare gains can be substantially

larger than those in the baseline model. Moreover, the optimal reform can be a Pareto improvement in the sense that it allows all types of agents to be better off. This result is rather surprising given that able agents have to pay additional taxes in the optimal system. Intuitively, if the labor supply is more elastic, it becomes less smooth over the life cycles as agents concentrate their labor supply in periods with high labor productivity. In the Korean allocation, this effect is so large that able agents may retire early due to relatively low labor productivity nearing mandatory retirement. Such an excessive response of labor supply creates a large efficiency loss, which is eliminated by the optimal reform. With a relatively elastic labor supply, the efficiency gain for able agents outweighs the utility costs due to the additional tax burden.

The findings of this paper have policy implications for Korea's DI programs. First, the current DI system does not adequately protect agents from partial and full disability, as indicated by substantial increases in the lifetime utility of disabled agents due to the optimal reform. According to the quantitative analysis, this problem can be mitigated by large increases in transfers to the disabled, which can be financed by small increases in taxes paid by the able. Second, under the current system, agents experience difficulty in coping with early and/or severe disability. If disabled early in the life cycle, agents have to reduce consumption significantly without sufficient DI benefits because they do not possess adequate wealth. For this reason, giving a larger amount of DI benefits to young disabled agents than to old ones can improve welfare.

This paper is most directly related to the literature on the optimal design of DI. Diamond and Mirrlees (1978) and Golosov and Tsyvinski (2006) analyzed the optimal DI when agents are identical except for privately observed disability. Lozachmeur (2006) and Lee (2015a) extended the analysis by allowing for heterogeneity in pre-disability labor productivity. In addition, Lee (2015a) quantified the welfare gains from replacing the U.S. SSDI with the optimal system. None of the aforementioned papers, however, take partial disability into account. Yin (2015) studied the effects of introducing partial disability benefits into the current SSDI with a dynamic life-cycle model, but she did not characterize the optimal allocation or conduct a welfare analysis. Other researchers such as Kitao (2014) and Low and Pistaferri (2015) assessed the welfare impacts of partial reforms in the U.S. DI system in rigorously calibrated dynamic models.

Methodologically, the current paper follows the New Dynamic Public Finance (e.g., Golosov, Kocherlakota, and Tsyvinski, 2003; Albanesi and Sleet, 2006) in the sense that the optimal design of a tax or social insurance program is analyzed in a dynamic model with private information.² Broadly, this paper is also associated with

² For an excellent overview of the New Dynamic Public Finance, see Golosov, Tsyvinski, and Werning (2006) and Kocherlakota (2010).

those that evaluate various tax and transfer programs quantitatively such as Conesa, Kitao, and Krueger (2009) and Weinzierl (2011). These papers, however, do not analyze DI, unlike the current paper. Regarding Korea's DI system, Lee (2015b) was the only one to evaluate the welfare effect of DI programs (to the best of my knowledge), but the paper is only concerned with full disability and related DI programs.

This paper is structured as follows. Section II reviews Korea's DI programs, and Section III introduces the model to assess the programs. Section IV describes the planner's social welfare maximization problem and characterizes the solution, that is, the optimal allocation. Section V incorporates Korea's DI programs into the model economy and finds the allocation under these programs. Section VI quantitatively compares the allocation in Korea with the resource-neutral optimal allocation in the calibrated model and quantifies welfare gains from the optimal reform. Finally, Section VII concludes.

II. Korea's Disability Insurance System

In this section, I provide a brief overview of DI programs in Korea that provide benefits to people with disabilities. I consider four programs in this paper: i) the disability allowances program for moderately disabled people, ii) the pension for disabled people program for severely disabled people, iii) the disability pension of the National Pension System (NPS), and iv) the basic pension for old-age retirees.

Before describing Korea's DI programs, I clarify the exchange rate used throughout this paper. All monetary values in this paper were originally expressed and calculated in South Korean Won (SKW) in 2010 prices. In consideration of readers unfamiliar with the currency, I express monetary values in U.S. dollars (USD). Throughout this paper, I use the exchange rate $1 \text{ USD} = 1000 \text{ SKW}$, because this is roughly the real exchange rate between the two currencies adjusted for the difference in the general price level and it makes the conversion straightforward.

Classification of people by degree of disability: In Korea, each registered disabled person is assigned a disability grade depending on the severity of his or her disability. Disability grades are 1 to 6, with 1 being most severe and 6 being least severe. A person with a grade 1 or 2 disability or with multiple grade 3 disabilities is classified as severely disabled under Korea's DI programs. This person is assumed to be fully disabled and is referred to as type 2 throughout this paper. A person with a grade 3 to 6 disability is classified as moderately disabled under Korea's DI programs. Such a person is assumed to be partially disabled and is referred to as type 1 in this paper.

People without any disability grade are called able, non-disabled, or type 0 in this paper and are ineligible for any government program for the disabled.

Disability allowances: The disability allowances program is aimed at moderately or partially disabled people. This program is called the disability benefit for partial disability or the type 1 (disability) benefit throughout this paper. It is a means-tested program as it provides \$40 monthly to a moderately disabled person if his or her asset-adjusted income does not exceed 120% of the minimum cost of living (MCL). In 2013, this program had approximately 320,000 beneficiaries, 68% of whom had an asset-adjusted income lower than the MCL.

Pension for disabled people: The pension for disabled people program provides monthly benefits to severely disabled people who lose their production capabilities completely or substantially. As this program is targeted at the severely disabled aged 18 to 64, it is referred to as the disability benefit for full disability or the type 2 (disability) benefit in the remainder of this paper. This program is also means tested. The combined asset-adjusted income of a severely disabled person and his or her spouse should not exceed an income threshold to be eligible for the benefits. In 2015, the monthly income threshold was \$930 for a single person and \$1,488 for a married couple.

Type 2 benefits consist of a base benefit and an add-on benefit. In 2015, the monthly base benefit was roughly the minimum of \$200 and the difference between the income threshold and asset-adjusted income. An add-on benefit is given depending on the income level as follows.

Asset-adjusted income (y^a)	Monthly add-on benefit
$y^a \leq \text{MCL}$	\$80
$\text{MCL} < y^a \leq 120\% \text{ of MCL}$	\$70
$120\% \text{ of MCL} < y^a \leq \text{income threshold}$	\$20

In 2013, the program had approximately 305,000 beneficiaries. Of these, 52.8% were in the lowest income bracket in the above table; 17.4%, the middle income bracket; 29.8%, the highest income bracket.

Disability pension of the NPS: Unlike type 1 and 2 disability benefits, the disability pension of the NPS provides benefits only to disabled people who have paid NPS contributions during their working years. NPS contributions include both DI and old-age retirement insurance components. Although benefits are calculated according to an old-age pension benefit formula, the actual amount differs depending on the disability grade. A person with a grade 1, 2, or 3 disability is

entitled to receive 100%, 80%, and 60%, respectively, of the basic old-age pension benefit every month. A person with a grade 4 disability will receive a one-time benefit of 225% of the basic old-age pension benefit. However, the disability grade in the NPS is completely different from that for type 1 and 2 disability benefits. Beneficiaries of the disability pension are only few in Korea because disability must be quite serious to qualify for the benefits.³ This fact indicates that the disability pension is likely to play only a limited role in insuring people against disability.

Basic pension: The basic pension is a means-tested welfare program targeted at people aged 65 or older. As of 2016, to qualify for basic pension benefits, monthly asset-adjusted income should not exceed \$1,000 for singles and \$1,600 for married couples. The amount of benefits is approximately \$200 for those without NPS benefits but can be reduced if beneficiaries of the program are currently receiving NPS benefits. Most disabled people are likely to receive benefits from this program. If a person has received type 2 disability benefits up to age 64, they are automatically replaced with the basic pension benefits at age 65. In addition, moderately disabled people aged 65 or older tend to have low income, and their NPS benefits tend to be quite low. As a result, most of them can qualify for the basic pension program.

III. Model

3.1. Setup

The economy is populated by agents who live for T periods. They can work up to period W unless fully disabled, but all agents should retire in period $W+1$. Their utility function is given as $u(c) - v(n)$, where c and n are consumption and labor, respectively. I assume that $u' > 0 > u''$ and $v', v'' > 0$ in addition to $v(0) = 0$. Production or labor income y is determined by the production function $y = \phi n$, where ϕ is the labor productivity. As $n = y / \phi$, the utility function can also be written as $u(c) - v(y / \phi)$.

In the model, agents differ in disability types. I denote the disability type and labor productivity in period t , respectively, by θ_t and ϕ_t . There can be three disability types $\{0, 1, 2\}$ for any t . First, $\theta_t = 0$ refers to an able agent in period t without disability and $\phi_t = \omega_t > 0$ for this type of agent. Second, $\theta_t = 1$ means a partially disabled agent in period t with productivity $\phi_t = \kappa \omega_t$. Parameter $\kappa \in (0, 1)$ represents the productivity of a partially disabled agent compared with that of an able one. Finally, $\theta_t = 2$ refers to a fully disabled agent who cannot

³ In 2013, the beneficiaries of the disability pension were only 78,034 (0.16% of the total population), and total benefits were merely 365 billion won (0.03% of GDP).

produce anything due to $\phi_i = 0$. Given that labor productivity ϕ_i depends solely on the disability type θ_i , I sometimes express $\phi_i = \phi_i(\theta_i)$ in this paper.

Disability types change over the life cycles with the following transition probabilities.

$$\pi(\theta_1) = \Pr(\theta_1), \quad \pi(\theta_t | \theta_{t-1}) = \Pr(\theta_t | \theta_{t-1}), \quad t \geq 2$$

Now, I define $\theta^t \equiv (\theta_1, \dots, \theta_t)$ as a type history up to period t and $\pi(\theta^t)$ as the unconditional probability of the history. Given the transition probabilities, that $\pi(\theta^t) = \pi(\theta_1)\pi(\theta_2 | \theta_1) \cdots \pi(\theta_t | \theta_{t-1})$ is straightforward.

Disability type θ_i is private information. I also assume both ϕ and n are privately observed, whereas y is publicly observed in the production function $y = \phi n$. If an agent produces $y_i > 0$, then others do not know whether he is able or partially disabled. In addition, if $y_i = 0$ for an agent, then others do not know whether he is fully disabled or just shirking even though he is able or only partially disabled. This information is available only to the agent himself. Therefore, if the government raises DI benefits for people with $y_i = 0$, then it may improve the welfare of fully disabled agents. However, doing so can also induce able and partially disabled agents to reduce their labor supply. In this way, this model captures the insurance–incentive or equity–efficiency trade-off, which is the key to understanding optimal DI. The assumption of private information seems reasonable because certain disabilities are invisible and difficult to either prove or disprove. Distinguishing between partial and full disability is even more difficult through medical screening tests. Therefore, I maintain the assumption of privately observed disability throughout this paper.⁴

Solving these types of dynamic models with private information is generally challenging. Therefore, I make a few assumptions on the evolution of disability types for tractability of the model. First, the disability status cannot improve over time: it can either deteriorate or be maintained. Formally, this assumption is written as

$$0 \leq \theta_t \leq \theta_{t+1} \leq 2. \quad (1)$$

For example, a fully disabled agent can only be fully disabled for the rest of his life, whereas a partially disabled agent may either continue to be partially disabled or become fully disabled in the next period. By contrast, an able agent can have any of

⁴ One can argue that determining true disability types is relatively easy in Korea through medical tests to determine eligibility for social welfare programs. Thus, I also consider the case in which all agents reveal their true types and evaluate the welfare gains from the optimal reform of the DI system in Section VI.

the three types in the next period. Although this assumption is adopted mainly for analytic simplicity, it tends to be satisfied in the available data sources.

Second, disability types are constant in retirement periods for any agent.

$$\theta_W = \theta_{W+1} = \dots = \theta_T \quad (2)$$

I make this assumption because DI programs in Korea are targeted mainly at the working-age population. After mandatory retirement, disabled agents receive benefits mostly from social welfare programs for the elderly. By (2), the lifetime type history θ^T is entirely determined by the type history in the working periods θ^W . Hence, I call θ^W simply the lifetime history in what follows.

Finally, I define the history index for future reference. Specifically, $I(\theta^W) \equiv (t_0, t_1, t_2)$ with $t_0 + t_1 + t_2 = W$ is the history index that corresponds to agents who are able for the first t_0 periods, partially disabled for the next t_1 periods, and fully disabled for the last t_2 periods. For example, $I(\theta^W) = (W, 0, 0)$ corresponds to an agent who is able for the whole working periods. In the quantitative analysis, I use $I(\theta^W)$ to refer to lifetime history θ^W because it is more convenient than θ^W itself with a large W .

3.2. Social Welfare Function and Resource Constraint

In this model, I evaluate social welfare using the utilitarian social welfare function in which the welfare weight of a type of agent coincides with its population share. To formulate the social welfare function, let $c(\theta^t)$, $y(\theta^t)$, and $n(\theta^t)$ denote consumption, production, and labor, respectively, for an agent with a history θ^t in period t . By the assumptions made above, $n(\theta^t)$ can be calculated as the following.

$$n(\theta^t) = \begin{cases} y(\theta^t) / w_t & \text{if } \theta_t = 0 \text{ and } t \leq W \\ y(\theta^t) / (\kappa w_t) & \text{if } \theta_t = 1 \text{ and } t \leq W \\ 0 & \text{if } \theta_t = 2 \text{ or } t > W \end{cases} \quad (3)$$

The expression suggests that $y(\theta^t) = 0$ for fully disabled agents or retirees because they cannot produce anything. With the allocation, I write the social welfare function as

$$SW = \sum_{t=1}^T \beta^{t-1} \sum_{\theta^t} \pi(\theta^t) [u(c(\theta^t)) - v(n(\theta^t))]. \quad (4)$$

This social welfare function is utilitarian because $\pi(\theta')$, the probability of a history θ' , can be interpreted as the population share of agents with the history if aggregate uncertainty does not exist.

To describe the resource constraint, I assume that agents can save or borrow at a net interest rate r in an external financial market. Finally, I also assume that the economy has an initial resource M in period 1. The resource constraint can then be written as

$$\sum_{t=1}^T q^{t-1} \sum_{\theta'} \pi(\theta') [c(\theta') - y(\theta')] \leq M, \quad (5)$$

where $q = 1/(1+r)$ is the discount factor. Notice that $n(\theta') = y(\theta') = 0$ if $\theta'_t = 2$ or $t > W$ in the social welfare function (4) and the resource constraint (5).

IV. Optimal Allocation

In this section, I characterize the optimal allocation of the model, which is the solution to the planner's problem. In particular, I describe the planner's problem and then analyze the properties of the optimal allocation.

4.1. Planner's Problem

A social planner maximizes the social welfare (4) subject to the resource constraint (5) and relevant incentive constraints. I formulate the planner's problem as a direct revelation mechanism in which agents report their disability types and the planner assigns them corresponding allocations. Specifically, the sequence of events in this economy is given as follows.

- 1) The planner announces a set of allocations for all types and periods.
- 2) Every period, each agent reports his disability type after observing the allocations.
- 3) An allocation is assigned to each agent according to his report.

In this mechanism, allocations depend on reported types because true types cannot be observed. To induce agents to reveal their types truthfully, the planner should design allocations in a way that truthful reports should make them at least as well off as any other false report. Such conditions are referred to as incentive-compatibility (IC) conditions. The planner can attain allocations only if they are both incentive compatible and resource feasible.

I formulate IC conditions recursively due to the dynamic nature of the model. To begin, let g_t and $g^t = (g_1, \dots, g_t)$ denote a report in period t and a report history up to period t , respectively. In addition, I define $c(g^t)$ and $y(g^t)$,

respectively, as consumption and production for an agent with a report history g^t . Obviously, $g^t = \theta^t$ if an agent reveals his true type in all periods. Although g_t can differ from θ_t , it should be consistent with the evolution of θ_t , which implies (i) $0 \leq g_t \leq g_{t+1} \leq 2$ because reported disability types should not improve and (ii) $g_t = g_W$ for $t > W$ as the types reported should be constant in retirement. Moreover, $\theta_t = 2$ should choose $g_t = 2$ because fully disabled agents cannot pretend to work.

Now, let $z(\theta^t)$ denote the expected sum of utility from period t for an agent with a true history θ^t and truth-telling report history $g^t = \theta^t$. It is defined recursively as follows:

$$\begin{aligned} z(\theta^T) &= u(c(\theta^T)) - v(n(\theta^T)) \quad \text{for } t = T, \\ z(\theta^t) &= u(c(\theta^t)) - v(n(\theta^t)) + \beta \sum_{\theta_{t+1} \geq \theta_t} \pi(\theta_{t+1} | \theta_t) z(\theta^{t+1}) \quad \text{for } t < T, \end{aligned}$$

where labor $n(\theta^t)$ is given in (3). The variable $z(\theta^t)$ represents the expected payoff from the truth-telling reporting strategy $g^t = \theta^t$.⁵

To complete the description of IC conditions, let $z(g^t | \theta^t)$ denote the expected sum of utility from period t for an agent with a type history θ^t and a report history g^t , provided that he optimizes his report in period $t+1$. Again, $z(g^t | \theta^t)$ is defined recursively as follows.

$$\begin{aligned} z(g^T) &= u(c(g^T)) - v(n(g^T | \theta_T)) \quad \text{for } t = T \\ z(g^t | \theta^t) &= u(c(g^t)) - v(n(g^t | \theta_t)) + \beta \sum_{\theta_{t+1} \geq \theta_t} \pi_{t+1}(\theta_{t+1} | \theta_t) \max_{g_{t+1}} \{z(g^{t+1} | \theta^{t+1})\} \\ &\quad \text{for } t < T, \end{aligned}$$

where $n(g^t | \theta_t)$ is the labor for a type θ_t and a report history g^t :

$$n(g^t | \theta_t) = \begin{cases} y(g^t) / w_t & \text{if } \theta_t = 0 \text{ and } t \leq W \\ y(g^t) / (\kappa w_t) & \text{if } \theta_t = 1 \text{ and } t \leq W \\ 0 & \text{if } \theta_t = 2 \text{ or } t > W. \end{cases}$$

Notice that labor $n(g^t | \theta_t)$ depends on report history g^t and true type θ_t . In addition, $\max_{g_{t+1}} \{z(g^{t+1} | \theta^{t+1})\}$ in the above equation suggests that an agent is optimizing his report in period $t+1$. For this reason, $z(g^t | \theta^t)$ can be interpreted as the maximum expected payoff to an agent with report history g^t .

⁵ $z(\theta^{t+1})$ in $z(\theta^t)$ suggests that the government incentivizes workers through the promise of high future consumption. Future promotion can play a similar role, as analyzed in Park (2016).

To ensure that all types of agents tell the truth, the following IC conditions should hold for any θ^t with $\theta_t \in \{0,1\}$ and $g_t \in \{0,1,2\} - \{\theta^t\}$.

$$z(\theta^t) \geq z((\theta^{t-1}, g_t) | \theta^t) \quad (6)$$

To interpret this condition, consider an able or partially disabled agent who has a history θ^t with $\theta_t \in \{0,1\}$.⁶ Assume that the agent has also been revealing his true disability types until period $t-1$, which means $g^{t-1} = \theta^{t-1}$. For this agent, the left-hand side (LHS) of (6) is the expected utility from the truthful report of his type in period t . By contrast, the right-hand side (RHS) is the maximum expected utility from a false report in period t that results in $g^t = (\theta^{t-1}, g_t)$ with $g_t \neq \theta_t$. If the IC condition (6) is satisfied, then an agent chooses to report his true type in period t as long as he has done so until period $t-1$. Moreover, if a set of allocations satisfies the IC condition (6) from period 1 to T , then all agents will be induced to reveal their types truthfully in all periods and the allocations can be attained. Notice that the IC conditions are only concerned with single deviations in which agents lie once about their disability types. This is because in any period, no agent has already lied in the past due to the IC conditions in the previous periods. Consequently, IC conditions associated with single deviations are sufficient to induce all agents to reveal their types truthfully in all periods.

With the IC conditions, I can describe the planner's problem formally. The planner maximizes the social welfare function (4) subject to the resource constraint (5) and the IC conditions (6) for all relevant θ^t and g^t . The solution to the planner's problem is referred to as the optimal allocation throughout this paper.

4.2. Characterization of the Optimal Allocation

This subsection explains the optimal allocation of consumption over time and between consumption and labor within a period. All optimality conditions in this subsection follow from the first-order conditions of the planner's problem. Therefore, I present and interpret these conditions without proof.

4.2.1. Consumption allocation over time

I discuss the intertemporal consumption allocation in terms of the marginal capital income tax rate (MCITR) $\tau_t^k(\theta^{t-1})$, which is defined as a marginal tax rate on the return to saving in period $t-1$ by an agent with θ^{t-1} . MCITR measures the distortions in the intertemporal consumption allocation, and $\tau_t^k(\theta^{t-1})$ is obtained from

⁶ IC condition is irrelevant to $\theta_t = 2$ as fully disabled agents cannot pretend to work.

$$u'(c(\theta^{t-1})) = \beta[1 - r(1 - \tau_t^k(\theta^{t-1}))] \sum_{\theta_i \geq \theta_{t-1}} \pi(\theta_i | \theta_{t-1}) u'(c(\theta^t)). \quad (7)$$

In a decentralized economy with $\tau_t^k(\theta^{t-1})$, this equation will be satisfied as the intertemporal Euler equation. Note that $\tau_t^k(\theta^{t-1}) = 0$ as a benchmark for any θ^{t-1} in the first best without private information.

I first present the following optimality condition for the fully disabled or retirees.

$$u'(c(\theta^{t-1})) = \beta(1+r)u'(c(\theta^t)) \text{ if } \theta_{t-1} = \theta_t = 2 \text{ or } t \geq W+1 \quad (8)$$

This condition is the standard intertemporal Euler equation that implies $\tau_t^k(\theta^{t-1}) = 0$. The intertemporal allocation is not distorted for fully disabled agents or retirees. For able or partially disabled agents in working periods, the inverse Euler equation should be satisfied for the optimal intertemporal allocation.

$$\frac{1}{u'(c(\theta^{t-1}))} = \frac{1}{\beta(1+r)} \sum_{\theta_i \geq \theta_{t-1}} \frac{\pi(\theta_i | \theta_{t-1})}{u'(c(\theta^t))}, \text{ for } \theta_{t-1} = 0, 1 \text{ and } t \leq W \quad (9)$$

This equation implies that saving should be discouraged for able or partially disabled agents because $\tau_t^k(\theta^{t-1}) > 0$. To illustrate why, I apply the Jensen's inequality to (9) because $1/u'(c)$ is a convex function of $u'(c)$. I then obtain the following inequality:

$$u'(c(\theta^{t-1})) < \beta(1+r) \sum_{\theta_i \geq \theta_{t-1}} \pi(\theta_i | \theta_{t-1}) u'(c(\theta^t)), \quad (10)$$

which, together with (7), implies $\tau_t^k(\theta^{t-1}) > 0$.

To understand the intertemporal distortion for the able and partially disabled, suppose that an agent reduces consumption and raises saving in $t-1$. The LHS and RHS of (10), respectively, represent the utility loss and gain from the perturbation. In a model without any friction, the loss and gain should be equalized, and the intertemporal Euler equation similar to (8) will hold. In the current model, however, the planner should take incentive provision into account as well. Specifically, if an able agent who increases saving in period $t-1$ continues to be able in period t , he is more tempted to falsely claim to be disabled to enjoy both more leisure and relatively high consumption financed by the saving. As a result of this effect, the planner finds inducing the agent to work increasingly difficult. Considering this incentive cost, the planner discourages saving and distorts the consumption allocation over time as in (10).

The distinction between the able or partially disabled in working periods and the

fully disabled or retirees can now be interpreted in terms of the intertemporal allocation. The intertemporal allocation for fully disabled or retired agents is left undistorted because their disability types do not change any further, and, hence, they no longer need to be incentivized. However, able or partially disabled agents in working periods may experience privately observed type changes and must be incentivized in the future. Such a consideration leads to distortions in their saving.

4.2.2. Consumption–labor allocation

I use the marginal labor income tax rate (MLITR) to measure the size of distortions in consumption–labor allocation. Specifically, let $\tau_t^y(\theta')$ denote the MLITR in period t for an agent with a type history θ' . MLITR is defined implicitly in the following equation.

$$\frac{v'(n(\theta'))}{u'(c(\theta'))} = \phi_t(\theta_t)(1 - \tau_t^y(\theta')) \quad (11)$$

Recall that $\phi_t(\theta')$ is the labor productivity for a type θ_t . The equation will be satisfied if an agent optimizes (c_t, n_t) given the MLITR τ_t^y . Without private information or any other friction, $\tau_t^y = 0$ will be obtained in the optimal allocation.

Now, I present the conditions for the optimal allocation between consumption and labor. For able agents in a working period $t \leq W$,

$$\frac{v'(y(\theta')/w_t)}{u'(c(\theta'))} = w_t = \phi_t(0) \text{ for } \theta' \text{ with } \theta_t = 0, \quad (12)$$

and for partially disabled agents in a working period $t \leq W$,

$$\frac{v'(y(\theta')/(\kappa w_t))}{u'(c(\theta'))} < \kappa w_t = \phi_t(1) \text{ for } \theta' \text{ with } \theta_t = 1. \quad (13)$$

Comparing (11) with the optimality conditions (12) and (13), I obtain $\tau_t^y(\theta') = 0$ for $\theta_t = 0$ and $\tau_t^y(\theta') > 0$ for $\theta_t = 1$. Labor allocation is distorted only for the partially disabled. The labor distortion arises due to private information. To observe this phenomenon, notice that able agents can quite easily pretend to be partially disabled by shirking. Hence, the planner should distort the allocation for the partially disabled to make it unattractive to able agents, which results in $\tau_t^y > 0$. Doing so can discourage deviation by able agents because they do not want to reduce labor at the cost of lower consumption. Thus, the labor allocation for partially disabled agents is characterized by $\tau_t^y > 0$. By contrast, partially disabled agents find mimicking able agents difficult because they will have to work more.

Considering this, the planner finds no reason to distort the allocation for the able and achieves $\tau_i^y = 0$.

V. Allocation under Korea's Disability Insurance System

I now turn to the Korean allocation, which is the equilibrium allocation under Korea's DI system. I first incorporate the DI programs into the model and describe the agent's problem under such programs. I then interpret their first-order conditions to characterize the Korean allocation qualitatively.

5.1. Social Welfare Programs Related to Disability in Korea

The government operates the programs discussed in Section II: type 1 disability benefits for partially disabled agents, type 2 disability benefits for fully disabled agents, the NPS disability pension, basic pension for old-age retirees, and a progressive income tax. Given the private information about disability type, benefits from these programs depend on agents' claims about the severity of disability in addition to their income levels. This means that benefit and resource allocations depend on the history of disability claims, i.e., $g^t = (g_1, \dots, g_t)$.

5.1.1. NPS disability pension

The government runs a pension system under which agents pay contributions while working and receive benefits if they retire in period $W+1$ or become disabled before that period. As discussed in Section II, only few disabled people receive disability pension benefits from the NPS in Korea, which indicates that disability needs to be severe for an agent to be eligible for the benefits. Thus, I assume that agents have to claim as fully disabled to receive disability pension benefits from the NPS.

The pension system is identical to the actual Korean NPS system. If an agent earns labor income y_t in period $t \leq W$, then he should pay the following NPS contribution to the government:

$$T_t^{nps} = \alpha \min(y_t, y_{\max}^{nps}), \quad \alpha \in (0, 1), \quad (14)$$

where α and y_{\max}^{nps} refer to an NPS contribution rate and maximum taxable earnings, respectively.

To describe NPS benefits, suppose that an agent reports full disability or retires in period m with a work history (y_1, \dots, y_{m-1}) . In the case of retirement, $m = W+1$, and he receives retirement pension benefits from the NPS. However, if

he reports as fully disabled in a certain period $m \leq W$, then he can receive disability pension benefits from the NPS. In any case, the agent receives NPS benefits B_t^m in period $t \geq m$. As in the actual system, the amount of NPS benefits is determined by the average labor income during working periods as follows:

$$B_t^m = B(\bar{y}_{m-1}) \text{ if } t \geq m, \text{ and } 0 \text{ if } t < m,$$

where \bar{y}_{m-1} is the average labor income during working periods.

$$\bar{y}_{m-1} = \frac{1}{m-1} \sum_{j=1}^{m-1} y_j$$

According to the above equation, the amount of NPS benefits is constant from period m onward. In the actual system, benefits for retired or disabled agents change every year because of inflation and wage growth. This feature is captured by the assumption of constant benefits because this model features no inflation or wage growth.

5.1.2. Disability benefits for fully and partially disabled agents

Type 1 and 2 disability benefits are given to agents who report partial disability ($g_t = 1$) or full disability ($g_t = 2$) in working periods. Such agents can receive benefits only if they pass relevant income tests in which the asset-adjusted income y_t^a is used to determine eligibility. Although this is in fact a complex function of various types of income and assets, I assume, for simplicity, that it is the sum of labor income, asset income, and NPS benefits, which is expressed as follows:

$$y_t^a = y_t + ra_t + B_t^m,$$

where a_t is the asset at the end of period $t-1$. Notice that the last term B_t^m can be positive only for agents with $y_t = 0$ who have already retired or claimed to be fully disabled.

Given an asset-adjusted income, an agent is qualified for a program relevant to his reported disability type provided that y_t^a does not exceed a corresponding income threshold. To formulate the disability benefits, let $D_t(g_t)$ denote the amount of disability benefits in period t for type g_t . It is calculated by the following formula.

$$D_t(g_t) = \begin{cases} d_1 & \text{if } g_t = 1, y_t^a \leq b_1, \text{ and } t \leq W \\ \min(b_2 - y_t^a, d_2) + d_2^A & \text{if } g_t = 2, y_t^a \leq b_2, \text{ and } t \leq W \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

In this formula, b_1 and b_2 are the upper bounds of the asset-adjusted income for benefits for partially and fully disabled agents, respectively, and d_2^A is an add-on benefit for the fully disabled, which is assumed to be independent of y_t^a for simplicity.

In the type 1 disability benefit program, if an agent claims to be partially disabled ($g_t = 1$), and his y_t^a does not exceed b_1 , then he can receive d_1 . Note that y_t^a does not affect the amount of benefits except for eligibility, and, hence, $\partial D_t(1) / \partial y_t^a = 0$. In the type 2 disability benefit program, basic benefits are designed to fill the gap between y_t^a and the income threshold b_2 with the maximum d_2 . The amount of basic benefits decreases one for one with y_t^a for the income range $y_t^a \in [b_2 - d_2, b_2]$, which implies that $\partial D_t(2) / \partial y_t^a = -1$. However, if $y_t^a > b_2$ or $y_t^a < b_2 - d_2$, then the amount of benefits is independent of y_t^a , meaning $\partial D_t(2) / \partial y_t^a = 0$. This feature can influence the saving decision in period $t-1$ because ra_t is a component of y_t^a .

5.1.3. Basic pension

The basic pension program exists for retirees with $t \geq W + 1$. It provides benefit Q_t according to the following formula.

$$Q_t = \begin{cases} d_{BP} & \text{if } y_t^a \leq b_{BP} \text{ and } t \geq W + 1 \\ 0 & \text{otherwise} \end{cases} \quad (16)$$

This formula indicates that all retirees who pass the income test (16) receive the same amount of benefits d_{BP} unlike in the actual program as discussed in Section II. Although this assumption is made for analytic simplicity, it is reasonable because y_t^a is much lower than b_{BP} for most beneficiaries of the basic pension in the calibrated version of this model discussed in Section VI.

5.1.4. Income tax

Income tax is not directly related to disability. Nonetheless, it is included in this model because the means-tested programs for disabled agents are funded by taxes, though indirectly, and a progressive income tax matters greatly for redistribution. To describe the income tax, I first define taxable income \tilde{y} as follows:

$$\tilde{y}_t = y_t + ra_t + B_t^m + D_t + Q_t - 0.5T_t^{nps}.$$

Taxable income includes all types of income with the worker's share of the NPS contribution deducted. Given \tilde{y} , the government collects an income tax T_t^{inc} by

$$T_t^{inc} = T^{inc}(\tilde{y}_t), \quad (17)$$

where T^{inc} is the income tax function.

5.2. Agent's Problem under Korea's DI Programs

To formulate the agent's problem under the social welfare programs described thus far, I first analyze the sequence of events of agents' life cycles and budget constraints together. In period 1, all agents enter the economy with a common asset a_1 . Subsequently, in every period, each agent observes his disability type θ_t and selects a type report g_t and allocation $\{c_t, y_t, a_{t+1}\}$. In choosing these variables, an agent takes into account the history of types and reports up to the previous period, θ^{t-1} , and g^{t-1} . Depending on the realization of disability history, some agents may claim (falsely) as fully disabled in a certain period m before the mandatory retirement. Finally, all agents should retire in period $W+1$. In the retirement periods, disability types remain constant. Hence, θ^W fully determines the type history θ^t for $t \geq W$.

The foregoing discussion indicates that agents' life cycles are divided into three stages partitioned by (m, W) . First, in period $t \leq m-1$, agents report as able or partially disabled. They provide labor supply but pay NPS contributions. The budget constraint for this stage is written as

$$c_t + a_{t+1} = y_t + (1+r)a_t + D_t(1) - T_t^{nps} - T_t^{inc}. \quad (18)$$

Recall that T_t^{nps} , $D_t(1)$, and T_t^{inc} are determined by (14), (15), and (17).⁷

In the second stage, $m \leq t \leq W$, agents claim to be fully disabled prior to the mandatory retirement. Agents do not work but receive disability pension benefits from the NPS. They can also receive type 2 benefits provided they pass the income test. The budget constraint for the second stage is written as follows:

$$c_t + a_{t+1} = (1+r)a_t + D_t(2) + B_t^m - T_t^{inc}. \quad (19)$$

⁷ Technically, all agents in this phase claim to be partially disabled due to private information on disability because such a claim is always beneficial: they can receive type 1 benefits in the case that $y_t^a \leq b_1$. However, this strategic behavior does not matter in the quantitative analysis because no able agents turn out to receive the type 1 benefits in the calibrated economy as their incomes are well above the threshold for the income test (15).

Note that some agents may not go through this stage if they keep working until period W .

Finally, in the retirement periods $t \geq W+1$, all qualified agents receive benefits from the NPS and the basic pension. The budget constraint for the final stage can be clearly given as

$$c_t + a_{t+1} = (1+r)a_t + Q_t + B_t^m + T_t^{inc}. \quad (20)$$

In this equation, B_t^m is interpreted as disability pension benefits if $m \leq W$ but as old-age pension benefits if $m = W+1$.

As agents begin to solve their problems after observing θ_1 in period 1, their expected lifetime utility can be written as follows:

$$\sum_{t=1}^T \beta^{t-1} \sum_{\theta'|\theta_1} \frac{\pi(\theta')}{\pi(\theta_1)} \left[u(c(\theta')) - v\left(\frac{y(\theta')}{\phi_t(\theta_t)}\right) \right], \quad (21)$$

where $y(\theta') = 0$ if $\theta_t = 2$ or $g_t \equiv g(\theta') = 2$. In this problem, the report history g^t is an important control variable that affects consumption, labor income, saving, and the period for a (false) report of full disability m , although it does not appear in this equation or in budget constraints. Indeed, $c(\theta')$ and $y(\theta')$ in (21) should be $c(\theta', g^t)$ and $y(\theta', g^t)$ as they depend on true history θ' and reported history g^t in principle. However, g^t is also a function of θ' , so consumption and production are written only in terms of θ' .

In sum, each agent with a period 1 disability type θ_1 maximizes (21) subject to budget constraints (18), (19), and (20). In the quantitative analysis, I characterize the Korean allocation that are solutions to the problems of various types of agents under the DI programs in Korea. To calculate social welfare in the Korean allocation, let $V(\theta_1)$ denote the value function of the problem for an agent with θ_1 . The level of social welfare can then be obtained as $\sum_{\theta_1=0}^2 \pi(\theta_1)V(\theta_1)$. Notice that this function coincides with the social welfare function (4) in Section III.

5.3. Characterization of the Korean Allocation

5.3.1. Intertemporal allocation

In this subsection, I analyze how consumption is allocated over time in the Korean allocation. I begin with the intertemporal Euler equation for retirees' consumption between two adjacent periods $t-1$ and $t \geq W+1$.

$$u'(c_{t-1}) \leq \beta[1+r(1-T_t^{inc})]u'(c_t) \text{ with equality iff } y_t^a \neq b_{BP}, \quad (22)$$

where $T_t^{inc'} \equiv dT_t^{inc} / d\tilde{y}_t$, i.e., the derivative of the income tax with respect to the taxable income. To interpret the equation, notice that the LHS and RHS of (22) represent the utility loss and gain, respectively, due to an additional saving in period $t-1$. In the case of an interior solution ($y_t^a \neq b_{BP}$), the two sides should be equated so that (22) may be an equality. However, if a_t is selected such that $y_t^a = b_{BP}$, then the RHS may exceed the LHS at the optimum because an additional saving leads to $y_t^a > b_{BP}$, which causes a discontinuous drop in basic pension benefits and c_t . With a corner solution with $y_t^a = b_{BP}$, (22) becomes an inequality. Notice, however, that regardless whether the solution is interior or boundary, (22) always implies that $\tau_t^k > 0$. This result confirms that the basic pension program discourages saving in retirement.

Similarly, agents who have already reported full disability or plan to do so in the next period choose c_{t-1} and c_t such that

$$u'(c_{t-1}) \leq \beta[1+r(1+D'_t(2))(1-T_t^{inc'})]u'(c_t) \quad \text{for } 2 \leq t \leq W,$$

where $D'_t(2) \equiv dD_t(2) / dy_t^a$. This equation can be interpreted straightforward because (c_{t-1}, a_t) in period $t-1$ affects $D_t(2)$ and T_t^{inc} in period t through $y_t^a = ra_t + B_t^m$. This equation can be further simplified depending on the eligibility for type 2 benefits, as summarized in the following lemma.

Lemma 1 *Suppose that an agent has already claimed as fully disabled by period $t-1$ or plans to do so in period t . The allocation of c_{t-1} and c_t is then characterized by the following equations in relation to the income test for type 2 benefits (15) in period t :*

1) If $y_t^a < b_2 - d_2$ or $y_t^a > b_2$,

$$\text{then } u'(c_{t-1}) = \beta[1+r(1-T_t^{inc'})]u'(c_t). \quad (23)$$

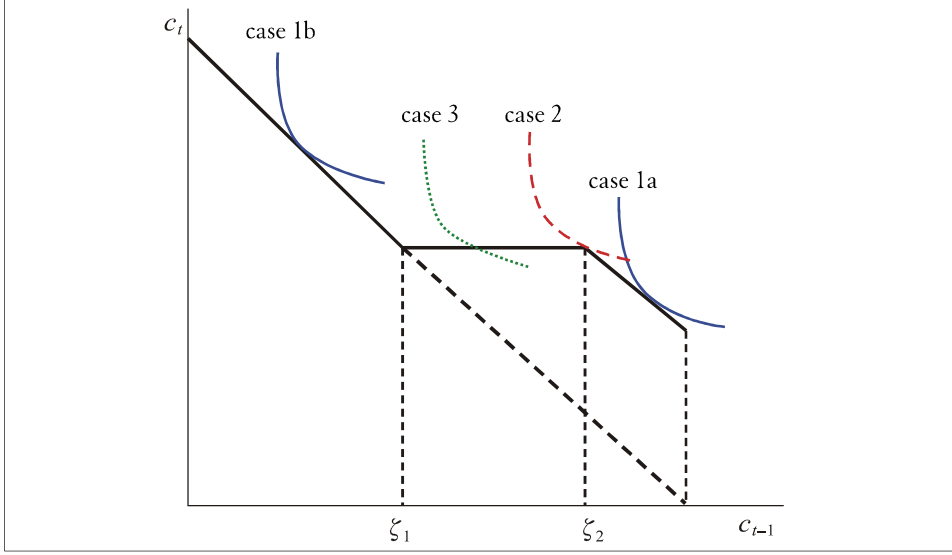
2) If $y_t^a = b_2 - d_2$,

$$\text{then } u'(c_{t-1}) < \beta[1+r(1-T_t^{inc'})]u'(c_t). \quad (24)$$

3) $b_2 - d_2 < y_t^a \leq b_2$ is impossible.

Figure 1 illustrates three cases shown in Lemma 1. I assume in the figure that $c_{t-1} = \zeta_1$ corresponds to $y_t^a = b_2$ in period t and $c_{t-1} = \zeta_2$ to $y_t^a = b_2 - d_2$. In case 1a in Figure 1, the solution to the agent's problem is interior with $c_{t-1} > \zeta_2$ and $y_t^a < b_2 - d_2$, which implies $D_t(2) = d_2$ and $D'_t(2) = 0$ because a change in y_t^a exerts no impact on $D_t(2)$. Similarly, in case 1b in Figure 1, the solution is interior and $D'_t(2) = 0$ though $D_t(2) = 0$ because $c_{t-1} < \zeta_1$ and $y_t^a > b_2$. In the two cases, the above Euler equation is simplified to (23) as in case 1 of Lemma 1. Notice that $\tau_t^k = T_t^{inc'}$ in this case by (7).

[Figure 1] Intertemporal Allocation



Note: This figure illustrates the intertemporal allocation for agents who have already claimed full disability as of period $t-1$ or who plan to do so in period t . For details about this figure, see the discussion related to Lemma 1 in Section V.

Case 2 in Figure 1 displays case 2 of Lemma 1. This case presents a corner solution together with $y_t^a = b_2 - d_2$ and $D_t(2) = d_2$. As the indifference curve is not tangential to the budget line in the figure, (24) is satisfied. This condition implies $\tau_t^k > T_t^{inc'}$ by (7). Figure 1 also shows why case 3 of Lemma 1 cannot be the solution to the agent's problem. If $\zeta_1 \leq c_{t-1} < \zeta_2$ so that $b_2 - d_2 < y_t^a \leq b_2$, then an agent can always increase lifetime utility by raising c_{t-1} because even if c_{t-1} goes up, c_t remains unaffected. A decrease in a_t due to the increase in c_{t-1} is fully offset by a rise in the type 2 benefit. For this reason, case 3 in Figure 1 with $D'_2(2) = -1$ cannot occur in the intertemporal allocation under Korea's DI system.

For able or partially disabled workers in period $t-1 \leq W-1$, the following intertemporal Euler equation includes expectation because of the uncertainty about their disability types in the next period:

$$u'(c_{t-1}) \leq \beta E_{t-1}[1 + r(1 + D'_t(g_t))(1 - T_t^{inc'})u'(c_t)], \quad (25)$$

where the expectation is taken over θ^t conditional on θ^{t-1} . Again, (25) becomes an inequality if at least one of the income tests for type 1 and 2 benefits is binding. In this equation, $g_t \in \{1, 2\}$ is the optimal choice of agents that depend on realized θ^t in period t . The value of the derivative $D'_t(g_t)$ is either 0 or -1 depending on g_t and y_t^a . The sign of τ_t^k implied by (25) is ambiguous even if it holds as an

equality. Thus, I offer certain conditions in Lemma 2 by which the sign of τ_t^k can be figured out.

Lemma 2 Define $\hat{r}_t \equiv r(1 + D'_t(g_t))(1 - T_t^{inc'})$. Suppose that no income test is binding in period t . The sign of τ_t^k is then related to $Cov_{t-1}[\hat{r}_t, u'(c_t)]$ as follows:

- 1) $\tau_t^k > 0$ if $Cov_{t-1}[\hat{r}_t, u'(c_t)] < (r - E_{t-1}(\hat{r}_t))E_{t-1}[u'(c_t)]$
- 2) $\tau_t^k < 0$ if $Cov_{t-1}[\hat{r}_t, u'(c_t)] > (r - E_{t-1}(\hat{r}_t))E_{t-1}[u'(c_t)]$
- 3) $\tau_t^k = 0$ if $Cov_{t-1}[\hat{r}_t, u'(c_t)] = (r - E_{t-1}(\hat{r}_t))E_{t-1}[u'(c_t)]$

Proof. I prove the first result, and other cases will simply follow. I rewrite (25) with a simple notation as follows:

$$u'(c_{t-1}) = \beta E_{t-1}[(1 + \hat{r}_t)u'(c_t)] = \beta[Cov_{t-1}(\hat{r}_t, u'(c_t)) + E_{t-1}(1 + \hat{r}_t)E_{t-1}(u'(c_t))].$$

By (7), $\tau_t^k > 0$ if $u'(c_{t-1}) < \beta(1 + r)E_{t-1}(u'(c_t))$. Combining it with the above equation, for $\tau_t^k > 0$,

$$Cov_{t-1}[\hat{r}_t, u'(c_t)] + E_{t-1}(1 + \hat{r}_t)E_{t-1}[u'(c_t)] < (1 + r)E_{t-1}[u'(c_t)],$$

or equivalently,

$$Cov_{t-1}[\hat{r}_t, u'(c_t)] < [r - E_{t-1}(\hat{r}_t)]E_{t-1}[u'(c_t)],$$

which concludes the proof.

Lemma 2 is an application of the standard asset-pricing argument. Even though the pre-tax interest rate is constant regardless of θ_t , the after-tax rate \hat{r}_t varies with θ_t because of the tax and transfer systems. If $Cov_{t-1}[\hat{r}_t, u'(c_t)]$ is strongly positive, as in case 2 of Lemma 2, \hat{r}_t tends to be high when c_t is low. This property makes the riskless bond a valuable insurance scheme against disability risk. In this case, that $\tau_t^k < 0$ is possible because the tax and transfer systems encourage agents to save more.

5.3.2. Labor allocation

The following equation characterizes the labor allocation under Korea's DI programs:

$$v' \left(\frac{y_t}{\phi_t} \right) = \phi_t u'(c_t) [1 - \Omega_1 + \Omega_2], \quad (26)$$

where

$$\begin{aligned} \Omega_1 &= T_t^{nps'} + T_t^{inc'}(1 - 0.5T_t^{nps'}), \\ \Omega_2 &= E_t \left[\sum_{j=m}^W B_j^{m'}(1 + D'_j(2))(1 - T_j^{inc'})\beta^{j-t} \frac{(u'(c_j))}{(u'(c_t))} + \sum_{j=W+1}^T B_j^{m'}(1 - T_j^{inc'})\beta^{j-t} \frac{(u'(c_j))}{(u'(c_t))} \right]. \end{aligned}$$

The Euler equation demonstrates that additional labor income has intratemporal and intertemporal effects. Suppose that y_t goes up in period t . First, the rise in y_t enables an agent to increase c_t by after-tax income. This effect is represented by $1-\Omega_1$ in (26). Moreover, the additional labor income leads to an increase in future NPS benefits because the average labor income in working periods \bar{y}_m goes up. The utility gains from this effect are captured by Ω_2 in (26), which indicates that the increase in future NPS benefits can affect future type 2 benefits and income tax payments. Note that m in Ω_2 is the period in which $g_j=2$ for the first time in the future and is therefore a control variable. It differs across type histories in the future.

Comparing (26) and (11), $\tau_t^y = \Omega_1 - \Omega_2$. As Ω_1 and Ω_2 are both likely to be positive, the sign of τ_t^y is ambiguous in theory. In Section VI, however, τ_t^y tends to be positive in the calibrated version of the model because the immediate effect Ω_1 is likely to dominate the intertemporal effect Ω_2 quantitatively.

VI. Quantitative Welfare Analysis

In this section, I calibrate the model with Korea's DI programs discussed in Sections III and V. With the calibrated model, I carry out a comprehensive welfare analysis of Korea's DI programs.

6.1. Calibration of the Model and Korea's DI Programs

6.1.1. Model parameters

In this subsection, I set the values of model parameters. I primarily use the Korean Labor and Income Panel Study (KLIPS) but also other data when the KLIPS does not provide information. The quantitative analysis is focused on agents aged 25 to 84, with 25–64 considered working age; 65–84, retirement age. The model period is set as 5 years, which implies that $W=8$ and $T=12$ and that period t corresponds to the age interval $[20+5t, 24+5t]$. Discount factors β and q are assumed 0.97 per annum so that $\beta(1+r)=1$.

To parameterize disability probabilities, information about the evolution of disability grades should be at the individual level. Unfortunately, the KLIPS does not provide such information. Hence, I calibrate disability probabilities to match key moments available in the aggregate data. To this end, I simplify the structure of disability probabilities by assuming that only two parameters, α_t and ψ , govern the probabilities. First, α_t is the probability that an able agent in period $t-1$ is still able in period t . Second, ψ is both the probability that a partially disabled agent remains partially disabled and that an able agent becomes partially disabled

[Table 1] Baseline Parameterization for Quantitative Analysis

Parameter	Value	Description
T	12	total number of periods (25–84 in actual age)
W	8	number of working periods (25–64 in actual age)
γ	6.20	relative risk aversion of leisure (to match Frisch elasticity 0.2)
ξ	0.060	relative importance of leisure (to match)
β	0.97 ⁵	utility discount factor (0.97 per annum)
q	0.97 ⁵	$(1+r)^{-1}$ with r being net interest rate ($\beta = q$)
$\{\alpha_t\}_{t=1}^W$	{0.985,0.995,0.994,0.993, 0.987,0.983,0.981,0.970}	Pr (able in t able in $t-1$)
ψ	0.920	Pr (partial disability in t partial disability in $t-1$)
κ	0.5	productivity of the partially disabled relative to the able
$\{w_t\}_{t=1}^W$	{55.71,70.46,77.80,79.53, 77.25,70.84,58.99,41.52}	labor productivity (unit: million won or thousand dollars in 2010)

given that he is newly disabled. In this sense, ψ governs the conditional probability of partial disability. Given the lack of related information, the parameter is assumed constant over time. Using these parameters, I can rewrite the model disability probabilities $\pi_1(\theta_1)$ and $\pi_t(\theta_t | \theta_{t-1})$

$$\begin{aligned} [\pi(0) \quad \pi(1) \quad \pi(2)] &= [\alpha_1 \quad \psi(1-\alpha_1) \quad (1-\psi)(1-\alpha_1)], \quad t=1 \\ \begin{bmatrix} \pi(0|0) & \pi(0|1) & \pi(0|2) \\ \pi(1|0) & \pi(1|1) & \pi(1|2) \\ \pi(2|0) & \pi(2|1) & \pi(2|2) \end{bmatrix} &= \begin{bmatrix} \alpha_t & 0 & 0 \\ \psi(1-\alpha_t) & \psi & 0 \\ (1-\psi)(1-\alpha_t) & 1-\psi & 1 \end{bmatrix}, \quad t \geq 2 \end{aligned} \tag{27}$$

Then, α_t and ψ are set to match the following numbers reported in the Ministry of Health and Welfare Statistical Yearbook 2013: the proportion of severely disabled agents in disabled agents, which is 21.81%, and the following proportions of able agents by age group.

Period	1	2	3	4	5	6	7	8
Age group	25– 29	30– 34	35– 39	40– 44	45– 49	50– 54	55– 59	60– 64
Fraction of able agents	0.985	0.980	0.974	0.967	0.954	0.938	0.920	0.892

Table 1 reports the resulting values of α_t and ψ .

Regarding κ , the ratio of productivity of the partially disabled to that of the able, I compare the average earnings of disabled and able workers. According to the Korea Institute for Health and Social Affairs (2015) and the employment statistics provided by the Korea Statistical Information Service, the average monthly labor

income is \$1,530 for disabled workers but \$3,230 for all workers although weekly working hours are almost identical regardless of disability status. This means that the average wage rate of disabled workers is approximately 47% that of able workers. Based on this information, I set $\kappa = 0.5$ as a baseline value. However, the productivity difference between able and disabled workers may be smaller than the wage gap due to disabled workers' other disadvantages. Therefore, I also use $\kappa = 0.7$ for the sensitivity analysis.

To calibrate w_t , I adopt the methodology in the literature on quantitative public finance (e.g., Lee, 2015a, 2015b; Huggett and Parra, 2010). Specifically, using the KLIPS from waves 7 to 15 (2004 to 2012), I first obtain real hourly wage from the monthly labor income and weekly labor hours at the main job of each respondent. I then regress this variable on a polynomial of age as follows:

$$\ln wage_{i,t} = \beta_0 + \sum_{k=1}^4 \beta_k (age_{i,t})^k + \text{time dummies} + \varepsilon_{i,t},$$

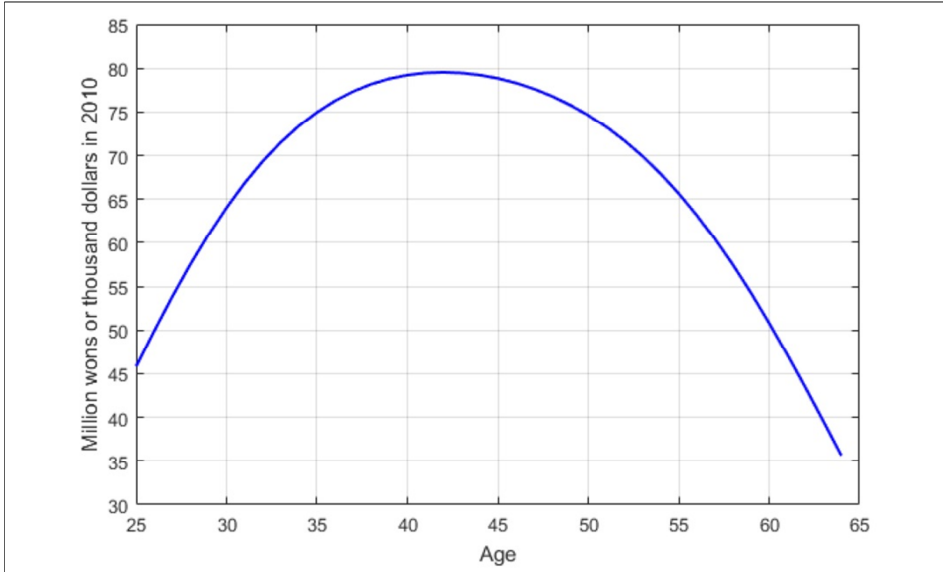
where $wage_{i,t}$ is the real hourly wage, $age_{i,t}$ is age, and $\varepsilon_{i,t}$ is the error term. As usual, i and t are indices for individual and time, respectively. Subsequently, w_t is calculated as

$$w_t = \exp \left[\hat{\beta}_0 + \sum_{k=1}^4 \hat{\beta}_k age^k \right].$$

To reduce the influence of outliers, I only use observations of people who are male and family heads aged 25–64 that appear in the sample at least three times. In addition, I exclude unreasonable observations with weekly labor hours less than 10 or greater than 112 as well as those with a real hourly wage less than half of the statutory minimum wage. All of those refinements are widely used in the literature.⁸ Figure 2 depicts the estimated skill profiles, which are hump shaped and peak around age 40. These features are largely in line with the findings in the literature on life-cycle earnings (Gourinchas and Parker, 2002).

⁸ See Weinzierl (2011) as well as the aforementioned papers.

[Figure 2] Estimated Skill Profiles over the Life Cycle



Note: This graph displays the amount of annual labor income if an able agent works for 16 hours every day.

Agents' preferences are represented by the CRRA utility function expressed as follows:

$$u(c) - v(n) = \ln(c) - \left[-\xi \frac{(1-n)^{1-\gamma} - 1}{1-\gamma} \right],$$

where γ is set to match the Frisch elasticity ε at the average labor hours \bar{n} . For this utility function, the Frisch elasticity is calculated as $\varepsilon = (1-\bar{n}) / (\gamma\bar{n})$. With this equation, ε and \bar{n} should be given to pin down γ . As for ε , I use 0.2, 0.5, and 0.8 following the U.S. standard due to the lack of empirical studies on the Frisch elasticity in Korea. Among these values, I take 0.2 as the baseline value as it matches the key labor market statistics in Korea, as will be evidenced later. I also impose $\bar{n} = 0.446$ in calculating γ because it is the median weekly labor hours in the KLIPS with the aforementioned refinements. Consequently, $\gamma = 6.20$ if $\varepsilon = 0.2$, $\gamma = 2.48$ if $\varepsilon = 0.5$, and $\gamma = 1.55$ if $\varepsilon = 0.8$. Finally, ξ is set to attain $\bar{n} = 0.446$ as an outcome of the calibration under Korea's DI system. This procedure yields $\xi = 0.06$ for $\varepsilon = 0.2$, $\xi = 0.60$ for $\varepsilon = 0.5$, and $\xi = 1.04$ for $\varepsilon = 0.8$. All of the parameter values discussed thus far are also summarized in Table 1.

6.1.2. Parameters related to the DI programs

National Pension System: As for the NPS contribution $T_t^{nps}(y)$, I set $\alpha = 0.09$, and $y_{\max}^{nps} = \$4,210$ per month in (14) following the actual NPS.⁹ The benefit function $B(\cdot)$ is also based on the actual benefit formula in the NPS but certain features of the actual formula are modified to reduce computational complexity. First, in the actual NPS benefit formula, the benchmark replacement ratio declines gradually every year until 2028. This paper is more concerned with the long-term welfare effect, so I take the system in 2028 in this model, and the benchmark replacement rate is 40%. Second, if an agent is fully disabled in this model, then he will receive the benefit equivalent to that which an old-age retiree with the same work history will receive. This is not the case in the actual NPS: the disability pension benefits can be 100%, 80%, or 60% of the old-age pension equivalent depending on the severity of disability. I simplify the formula because only one type of disability, that is, full disability, qualifies for the NPS disability pension in this model. Except for these adjustments, the benefit function used here is identical to the actual NPS benefit formula.

Specifically, if an agent claims as fully disabled for the first time in period m , then he will receive the following NPS benefit in every period following period m .

$$B(\bar{y}_{m-1}) = \frac{1.2(A + \bar{y}_{m-1})[1 + 0.05\{5(m-1) - 20\}]}{12}, \quad (28)$$

where A denotes the economy-wide average labor income. As in the actual formula, the benefit depends on both economy-wide average earnings A and the agent's average earnings \bar{y}_{m-1} . In addition, (28) suggests that the replacement rate rises with years worked, $5(m-1)$, as one model period translates to 5 years. To match the B function to the actual system, I assume that $A = \$1,855$ in 2010, which is equivalent to the actual value of A in 2015 (\$2,045).

Means-tested DI programs: I set five parameters $(d_1, d_2, d_2^A, b_1, b_2)$ in the formula for type 1 and type 2 disability benefits (15) according to the actual programs in 2015. I select $d_1 = \$40$ and $b_1 = \$741$ for $D_t(1)$, and $d_2 = \$200$ and $b_2 = \$741$ for $D_t(2)$. I also assume the add-on benefit $d_2^A = \$80$ is independent of y_t^a for computational simplicity. This approximates the actual program reasonably. As discussed in Section II, 53% and 17% of recipients of the type 2 benefits, respectively, receive \$80 and \$70.

⁹ In the quantitative analysis, I express all variables in 2010 real values. All values presented here are actually deflated to 2010 real values unless specified otherwise.

Income tax function: The approximation of the income tax function $T^{inc}(y)$ is based on the comprehensive income tax data, which include the total income and tax liability for each income percentile in 2011. In particular, I estimate the following equation:

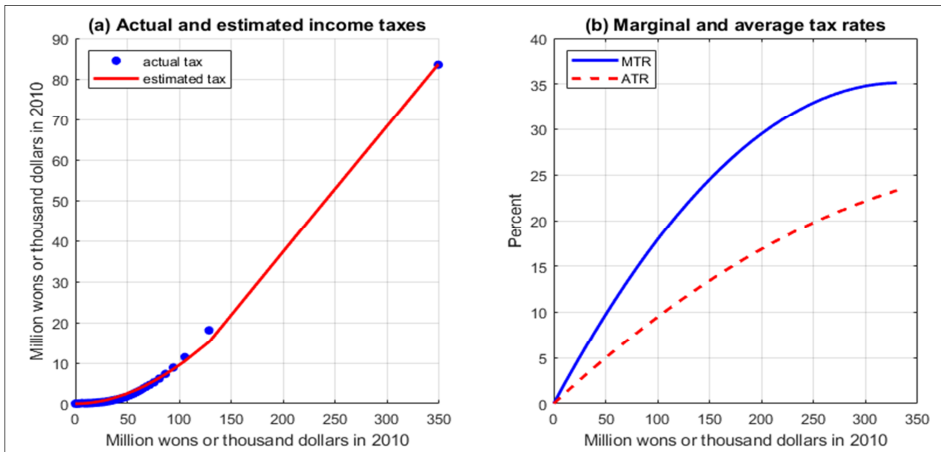
$$Tax_j = a_2(Y_j)^2 + a_3(Y_j)^3 + e_j$$

where Y_j , Tax_j , and e_j denote the total income, the tax liability, and an error term for j^{th} percentile, respectively. As shown in panel (a) of Figure 3, this equation fits the data extremely well with $R^2 = 0.997$. Using the estimates of a_2 and a_3 , I adopt the following income tax function in the quantitative analysis:

$$T^{inc}(\tilde{y}) = \hat{a}_2(\tilde{y})^2 + \hat{a}_3(\tilde{y})^3,$$

where (\hat{a}_2, \hat{a}_3) are estimated (a_2, a_3) in the regression equation. Estimated T^{inc} in Figure 3 features two properties of the actual income tax: non-negative and progressive in terms of marginal and average income tax rates.

[Figure 3] Estimated Income Tax Function



Note: Panel (a) shows the estimated income tax function, and panel (b) displays the implied marginal and average income tax rates.

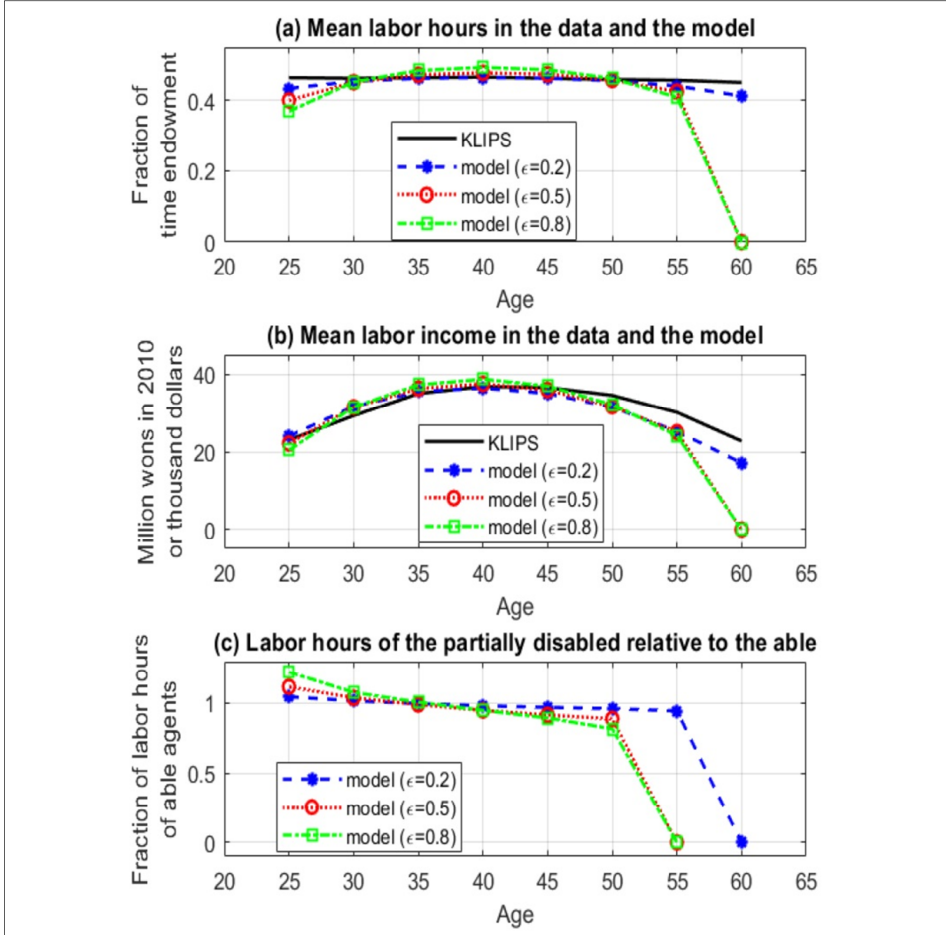
Basic pension: The benefit formula of the basic pension (16) also follows the actual program in 2015. I choose $d_{BP} = \$200$ monthly and $b_{BP} = \$1,000$.

6.1.3. Earnings and labor hours in the model and KLIPS

For the calibrated model to be valid, it should be able to match with the key labor statistics in Korea. I examine the validity by comparing labor income and hours

between the calibrated model and the KLIPS because the information about these variables is available from the KLIPS. Figure 4 reports the results.

[Figure 4] Labor Hours and Earnings in the Data and the Model



Note: ϵ denotes the Frisch elasticity. Age p represents the age interval $[p, p+4]$, which in turn corresponds to the model period $t = (p-20)/5$. Panels (a) and (b) exhibit average n_t and y_t in the model and corresponding values in the KLIPS. The averages in the model only include agents who provide labor supply. Panel (c) displays the ratio of n_t for an able agent to average n_t for partially disabled agents with $n_t > 0$. For parameter values other than ϵ used to calibrate the model, refer to Table 1.

Panel (a) of Figure 4 compares the average labor hours between the KLIPS and the model with three different values of the Frisch elasticity ϵ . The average labor hours from the KLIPS are almost constant around 0.46. The calibrated model replicates this feature most closely when $\epsilon = 0.2$. In the model with ϵ equals 0.5 or 0.8, average labor hours exhibit greater variations over the life cycle and become

zero for agents aged 60–64, unlike in the data.¹⁰ A similar tendency can be observed for average labor income in panel (b) of Figure 4. Calibrated average labor earnings are most similar to the corresponding values in the KLIPS when $\varepsilon = 0.2$. From these results, the calibrated model with $\varepsilon = 0.2$ fits the average hours and labor income in the KLIPS best.

Another key feature in the labor markets is that although non-disabled and disabled workers exhibit a noticeable difference in their average earnings, their average labor hours are nearly identical, as discussed earlier.¹¹ To verify if the calibrated model accounts for this feature, I present the ratio of the labor hours of able workers to the average labor hours of partially disabled workers in the model in panel (c) of Figure 4. If $\varepsilon = 0.2$, then the ratio is very close to 1, except for period W , whereas it is quite different from 1 if ε equals 0.5 or 0.8. The ratio should be close to 1 according to the data, so the model with $\varepsilon = 0.2$ is the most consistent with the fact that average labor hours are similar between able and disabled workers.

Overall, the calibrated model with ε set to 0.2 accounts for the stylized facts on labor of able and disabled agents in the data most successfully. Consequently, I take the model with $\varepsilon = 0.2$ as the baseline model in the quantitative welfare analysis, though I also use 0.5 and 0.8 as alternative values of the Frisch elasticity for robustness checks.

6.2. Fully Optimal Reform and No-redistribution Reform

In the welfare analysis, I measure welfare gains from two reforms of Korea's DI system: the optimal reform and the no-redistribution (NR) reform. To do so, I first obtain the Korean allocation (c^{kr}, n^{kr}, y^{kr}) from the agents' problems in Section V. I then calculate the following variables for the welfare analysis.

$$M^{kr}(\theta^W) = \sum_{t=1}^T q^{t-1} [c^{kr}(\theta^t) - y^{kr}(\theta^t)], \quad \theta^t \leq \theta^W$$

$$M^{kr} = \sum_{\theta^W} \pi(\theta^W) M^{kr}(\theta^W) = \sum_{t=1}^T q^{t-1} \sum_{\theta^t} \pi(\theta^t) [c^{kr}(\theta^t) - y^{kr}(\theta^t)]$$

$M^{kr}(\theta^W)$ is the lifetime net consumption for an agent with a lifetime history θ^W as it measures the difference between lifetime consumption and lifetime labor income. $M^{kr}(\theta^W)$ can also be interpreted as government transfers to the agent because the net consumption should be financed by government transfers due to zero initial asset. M^{kr} is the weighted sum of $M^{kr}(\theta^W)$, which represents the

¹⁰ As will be confirmed later, no agents aged 60–64 supply labor in the model with $\varepsilon = 0.5$ or $\varepsilon = 0.8$.

¹¹ In this discussion, I exclude non-workers from the calculation of the average hours.

amount of resources or total government transfers required for the Korean allocation.

Following, I compute the optimal allocation that corresponds to the Korean allocation. The planner maximizes social welfare (4) subject to the resource constraint (5) with $M = M^{kr}$ imposed and IC constraints (6). The solution to this problem, (c^*, n^*, y^*) , is the optimal allocation corresponding to the Korean allocation because it maximizes social welfare among the incentive-compatible and feasible allocations that require M^{kr} . I also refer to optimal reform as changes in DI programs that can attain the optimal allocation.

NR allocation refers to the optimal allocation without redistribution. It is obtained from a modified planner's problem with *NR constraints*, No redistribution:

$$\sum_{t=1}^T q^{t-1} [c(\theta^t) - y(\theta^t)] = M^{kr}(\theta^W), \text{ for all } \theta^W, \quad (29)$$

in addition to the resource constraint (5) with $M = M^{kr}$ and IC constraints (6). The solution to the modified planner's problem will be called the NR allocation and denoted by (c^{nr}, n^{nr}, y^{nr}) . Policy changes that can achieve it are referred to as the NR reform.

Given the no-redistribution constraints (29), net lifetime consumption in the NR allocation should be the same as in the Korean allocation for every lifetime history. The NR reform does not allow redistribution across different types of agents although it allows reallocation of resources within each lifetime history to reduce inefficiency. Although it can improve efficiency in the resource allocation under Korea's DI system, the NR reform cannot generate any equity gain. By contrast, the fully optimal reform can generate equity and efficiency gains as the planner can redistribute resources freely across agents. Based on this distinction, I can decompose welfare gains from the optimal reform into efficiency and equity gains. The efficiency gain is captured by the welfare improvement through the NR reform, whereas the equity gain is measured by the difference in welfare gains between the optimal and NR reform.

To formalize the idea, let Φ^j denote a consumption-equivalent measure of welfare gains from a reform j . It can be calculated from the following equation:

$$\begin{aligned} & \sum_{t=1}^T \beta^{t-1} \sum_{\theta^t} \pi(\theta^t) [u(c^j(\theta^t)) - v(n^j(\theta^t))] \\ &= \sum_{t=1}^T \beta^{t-1} \sum_{\theta^t} \pi(\theta^t) [u(c^{kr}(\theta^t)(1 + \Phi^j)) - v(n^{kr}(\theta^t))], \end{aligned}$$

where (c^j, n^j, y^j) denotes the allocation from the reform j . Each side of the

equation represents the social welfare under the respective allocation, so Φ^j can be interpreted as the percentage increase in consumption for all types of agents to make the Korean allocation as good as the allocation j . Seeing that this measure can quantify the welfare gains from a reform, I calculate Φ^* and Φ^{nr} in the calibrated model. As discussed, Φ^* represents the welfare gains from the optimal reform, which in turn are decomposed into the efficiency gain Φ^{nr} and the equity gain $\Phi^* - \Phi^{nr}$.

6.3. Welfare Analysis with the Baseline Model

In this subsection, I discuss the results of the quantitative welfare analysis with the baseline parameters. I present Φ^* and characterize Korean and optimal allocation quantitatively to understand the sources of the welfare gains.

[Table 2] Summary of Calibration Results

	[1] baseline	[2] middle ε	[3] high ε	[4] high κ	[5] public info					
Frisch elasticity (ε)	0.2	0.5	0.8	0.2	0.2					
Relative productivity of the partially disabled (κ)	0.5	0.5	0.5	0.7	0.5					
A. Welfare gains (%)										
Optimal reform (Φ^*)	1.17	2.34	1.63	0.88	1.13					
Efficiency gain (Φ^{nr})	0.31	1.55	0.68	0.28	0.17					
Equity gain ($\Phi^* - \Phi^{nr}$)	0.86	0.79	0.95	0.60	0.96					
B. Retirement ages for agents without full disability										
$I(\theta^W)$; partially disabled since	KR	FO	KR	FO	KR	FO	KR	FO	KR	FO
(8,0,0): never	65	65	60	65	60	65	65	65	65	65
(7,1,0): age 60	60	65	60	65	60	60	60	65	65	65
(6,2,0): age 55	60	65	55	65	55	60	60	65	65	65
(5,3,0): age 50	60	65	55	65	55	60	60	65	65	65
(4,4,0): age 45	60	65	55	65	55	60	65	65	65	65
(3,5,0): age 40	60	65	55	65	55	60	65	65	65	65
(2,6,0): age 35	60	65	55	65	55	60	65	65	65	65
(1,7,0): age 30	60	65	55	65	55	60	65	65	65	65
(0,8,0): age 25	60	65	55	65	50	60	65	65	65	65

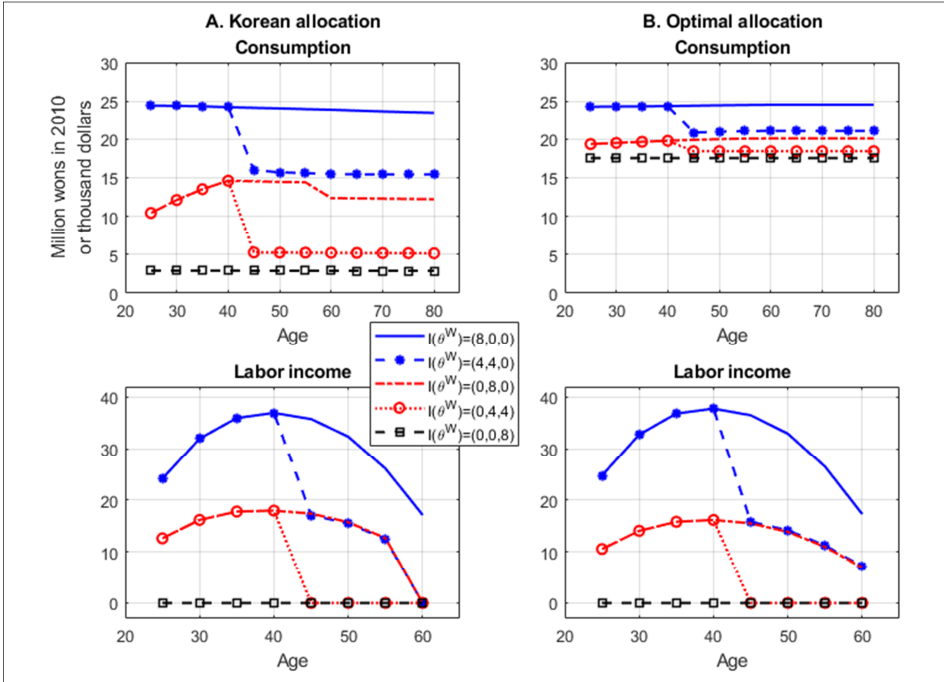
Note: Φ^j is the size of the welfare gains from a reform j to Korea's DI system. It is measured as a percentage change in consumption for all types of agents that will have the same effect on social welfare as the reform j . $I(\theta^W) = (t_0, t_1, t_2)$ is the index for lifetime history θ^W , which means that an agent is able in the first t_0 periods, partially disabled for the next t_1 periods, and fully disabled for the last t_2 periods of the working period. $W = 8$ in the calibration. The retirement age is calculated as $20 + 5t_r$, where t_r is the retirement period in the model. KR and FO refer to the Korean and fully optimal allocations.

6.3.1. Welfare gains from the optimal and NR reforms

Table 2 presents Φ^* and Φ^{nr} for several combinations of ε and κ . In column [1] of the Table, $\Phi^* = 1.17\%$ in the baseline model. This means the optimal reform will have the same welfare effect as a 1.17% increase in consumption for all agents in the economy. Such welfare gains seem quantitatively significant considering that this model is only concerned with the disability risk, abstracting from all other risks over the life cycle.

The size of the welfare gains looks broadly in line with that in the related papers. For instance, Lee (2015a) quantified the welfare gains from optimal reform of U.S. social security and income tax. He found the size of welfare gains to be equivalent to a 2.02% rise in consumption. Lee (2015b) also applied a similar methodology to Korea's NPS and found that $\Phi = 1.61\%$. Unlike the current paper, the aforementioned papers do not consider partial disability but take pre-disability differences in productivity into account. In addition, Lee (2015b) ignored type 1 and 2 disability benefits in calibrating Korea's DI system. Considering these differences, the size of the welfare gains found in the current paper is deemed consistent with the findings of previous papers.

[Figure 5] Consumption and Labor Income



Note: Age p represents the age interval $[p, p+4]$, which in turn corresponds to the model period $t = (p-20)/5$. $I(\theta^W) = (t_0, t_1, t_2)$ is the index for lifetime history θ^W , which means that an agent is able in the first t_0 periods, partially disabled for the next t_1 periods, and fully disabled for the last t_2 periods of the working period.

The welfare gains from the optimal reform can be decomposed using the welfare gains from the NR reform. In the baseline model, $\Phi^{nr} = 0.31\%$, which is 26.6% of Φ^* . Hence, 26.6% of the welfare gains from the optimal reform can be attributed to the efficiency gain and 73.4% to the equity gain through redistribution across agents. This result suggests that the optimal reform improves social welfare mainly by providing better insurance for agents with disabilities. Put it differently, Korea's current DI programs do not seem to provide sufficient insurance against disability.

6.3.2. Comparison between the Korean and optimal allocations

The comparison between Φ^* and Φ^{nr} helps to quantify the potential welfare improvement due to the optimal reform and the contributions of the equity and efficiency gains. For better understanding of the sources of the welfare gains, however, the Korean and optimal allocations should be analyzed. In this subsection, I characterize the Korean allocation in comparison with the optimal allocation in the baseline model.

Consumption across disability types: I first examine consumption paths for various disability histories to evaluate the insurance effects of Korea's DI programs. If agents are adequately protected from the disability risk, then their consumption will not fall significantly after disability, and consumption gaps between able and disabled agents will be small. Such consumption gaps can be used as an indicator for social protection for disabled agents.

Based on this idea, I present consumption paths for selected disability histories in both the Korean and optimal allocations in the upper panels of Figure 5. The figure demonstrates that consumption exhibits larger differences across disability types in the Korean allocation than in the optimal allocation. For example, consumption for people aged 25–29, $c(\theta^1)$, is very low for partially and fully disabled agents, and consumption drops considerably whenever the disability status worsens in the Korean allocation. Therefore, disability, whether partial or full, reduces the utility of agents in Korea substantially despite various DI programs. By contrast, in the optimal allocation, consumption does not decrease much even after disability. This finding clearly indicates that agents are not sufficiently insured against disability under the current DI system of Korea.

Disabled agents not protected well in Korea mainly because the amount of benefits paid by the various DI programs are too small for disabled agents to absorb the disability shock. In the case of partial disability, type 1 benefits are the only additional income from the government. The benefits, however, amount to \$480 annually, which is less than 2% of pre-disability consumption, even if agents pass the income test. The amount is far from sufficient to compensate for the 50% drop in labor productivity due to partial disability. As a result, partially disabled agents must reduce consumption significantly. Moreover, they tend to increase their labor

supply excessively to “help themselves” in response to the disability shock, which can be a source of inefficiency in the labor supply. This point can be seen in the lower panels of Figure 5 by comparing the labor income path for $I(\theta^W) = (0, 8, 0)$, i.e., agents who are partially disabled for the whole working periods, between the two allocations.

The government provides type 2 benefits and NPS disability pension to fully disabled agents. Total benefits from the two programs tend to be much larger than those for the partially disabled because type 2 benefits amount to \$3,050 annually at the maximum and the disability pension replaces a certain fraction of the pre-disability labor income. Nonetheless, such benefits are likely to be insufficient because fully disabled agents cannot work. Consumption paths for fully disabled agents, $I(\theta^W) = (0, 4, 4)$ and $(0, 0, 8)$, are significantly lower in the Korean allocation than in the optimal allocation as displayed in the upper panels of Figure 5. In particular, lifetime consumption can be extremely low for agents who become fully disabled early in their life cycles, e.g., $I(\theta^W) = (0, 0, 8)$, because they cannot receive disability pension benefits from the NPS nor do they accumulate assets to self-insure against disability.

The discussion thus far suggests that the government should increase the support to partially and fully disabled agents so that their consumption may not fall too much after disability. A simple way is to raise the benefits from the DI programs, although other policy instruments can also be used. Some may oppose to the benefit increase for disabled agents because it can exert undesirable incentive effects on able agents. That is, overly generous DI benefits can induce able agents to work less and, hence, reduce the total production of the economy. This argument can be evaluated based on the optimal allocation. Recall that the optimal allocation offers maximum DI *subject to IC constraints that able agents should be induced to work hard*. The optimal allocation does not allow excessively generous consumption for disabled agents to the extent that able agents may be tempted to shirk. This means that if consumption for disabled agents in a certain allocation is much lower than it will be in the optimal allocation, then a moderate increase in DI benefits is improbable to violate the IC constraints for able agents. As consumption for disabled agents in the Korean allocation is hardly close to consumption in the optimal allocation, an increase in DI benefits is likely to improve social welfare without meaningful incentive effects on the labor supply of able agents.

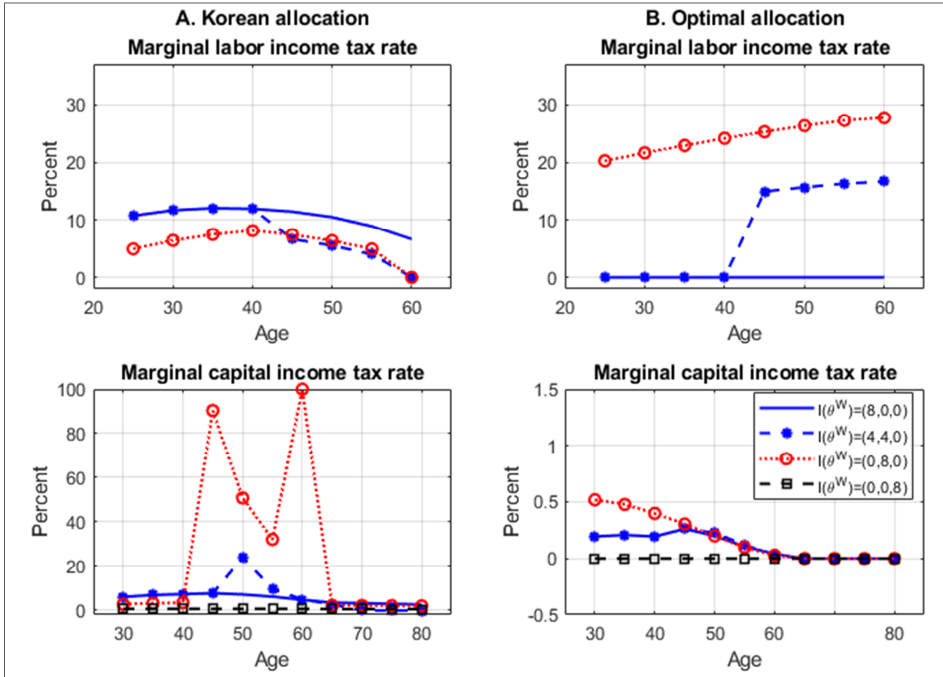
Labor allocation: I investigate $n(\theta')$ and $y(\theta')$ in the Korean allocation relative to the optimal allocation to analyze the nature of the efficiency gain from the optimal reform. In the lower panels of Figure 5, labor allocation under Korea’s DI system exhibits a few stylized facts that highlight distortions in Korea’s labor allocation.

First, the production of able agents in the Korean allocation is 1%–3% lower than

in the optimal allocation in any working period $t \leq W$, as shown in the lower panels of Figure 5. This finding implies unnecessary labor distortions for able agents under Korea's DI system. This point is confirmed in the upper panels of Figure 6, which show that for θ' with $\theta'_t = 0$, $\tau^y(\theta')$ should be zero but is actually positive in the Korean allocation. The positive MLITRs discourage able agents' labor supply and reduce their production compared with the optimal allocation. The decrease in production is interpreted as an efficiency cost of the current Korean DI system.

The positive MLITRs for able agents are interesting in themselves. As discussed above, (26), i.e., the condition for labor supply in the Korean allocation, does not restrict the sign of the MLITR. It can be negative, for example, if additional NPS benefits due to additional labor income are sufficiently large. In the calibrated model, however, such an intertemporal effect of the labor supply (Ω_2 in (26)) is dominated by the intratemporal distortion due to the income tax and the NPS contribution (Ω_1 in (26)). Hence, although τ^y_i can be negative in theory, it is actually positive, around 10%, for able agents in the Korean allocation.

[Figure 6] Marginal Labor and Capital Income Tax Rates



Note: Age p represents the age interval $[p, p+4]$, which in turn corresponds to the model period $t = (p-20)/5$. $I(\theta^W) = (t_0, t_1, t_2)$ is the history index for an agent who is able in the first t_0 periods, partially disabled for the next t_1 periods, and fully disabled for the last t_2 periods of the working period. For the definitions of marginal labor and capital income tax rates, see Section IV.

The second stylized fact in Figure 5 is that partially disabled agents choose to retire too early in period W or at age 60. The lower-left panel of the figure shows that $y_W = 0$ for $I(\theta^W) = (4, 4, 0)$ or $(0, 8, 0)$ in the Korean allocation. This result is in fact general: according to column [1] of Table 2, no partially disabled agents work in period W in the Korean allocation. The early retirement of partially disabled agents is in stark contrast to the optimal retirement period. Column [1] of Table 2 and the lower-right panel of Figure 5 confirm that working until period W and retiring in period $W+1$ or at age 65 are optimal for partially disabled agents. Such differences indicate another efficiency cost under Korea's DI system.

The last stylized fact is that partially disabled agents work too much prior to the early retirement relative to the social optimum. Figure 5 shows that $y(\theta')$ with $\theta_i = 1$ in the Korean allocation exceeds the optimal levels by more than 10% in any period prior to the early retirement. Such an excessive labor supply by relatively young agents with partial disability is motivated by the income loss due to partial disability itself and voluntary early retirement. In this sense, the second and third stylized facts are closely associated.

Together, the second and third stylized facts reveal an interesting finding regarding the intertemporal allocation of labor for partially disabled agents. In the optimal allocation, such agents should spread their labor supply over all working periods, from 1 to W , to smooth labor disutility over the life cycles. Under Korea's DI system, however, they provide labor supply only in the early working periods, from 1 to $W-1$, in which labor productivity is relatively high, and then give up labor income in period W because labor productivity is too low. This lack of "labor smoothing" causes excessive labor disutility over the life cycles. To reduce the excessive labor supply of young and middle-aged agents with partial disability, the MLITRs on their labor income should be much higher as in the optimal allocation presented in the upper-right panel of Figure 6. The Korean allocation cannot achieve this goal because partially disabled agents do not earn much and the MLITR tends to be low due to progressivity of the income tax.

Consumption allocation over time: I analyze the intertemporal allocation using the lower panels of Figure 6, which displays τ_i^k for the Korean and optimal allocations. In general, the MCITRs tend to be much larger in the Korean allocation, which reflects excessive intertemporal distortions. The reduction of the distortions accounts for part of the efficiency gain from the optimal reform.

Figure 6 also verifies the theoretical findings discussed in Sections IV and V. The figure confirms that $\tau_i^k = 0$ for fully disabled agents and retirees in the optimal allocation but positive in the Korean allocation in the figure. This result is consistent with (8) in the optimal allocation and (22)–(24) in the Korean allocation. Figure 6 also reveals that the optimal τ_i^k is positive for able or partially disabled agents, which is implied by (10) for incentive consideration.

As opposed to these results, the positive τ_i^k for able and partially disabled workers in the Korean allocation in the lower-left panel of Figure 6 should be interpreted with care. First, τ_i^k is moderately positive in some cases in the figure. This happens when the solution is interior and (25) holds as an equality. Lemma 2 indicates that the covariance between $u'(c_i)$ and $r(1+D'_i(g_i))(1-T_i^{inc'})$ is relatively small in these cases. On the contrary, in other cases, τ_i^k is unusually large and even equal to 100%. This occurs when the agents' problems yield a corner solution and the income test for type 2 benefits (15) is binding. In this case, the intertemporal Euler equation (25) is satisfied as a strict inequality and τ_i^k becomes unusually large. This result indicates that the intertemporal allocation of some agents under Korea's DI system is considerably distorted due to the income tests for type 1 or 2 disability benefits.

6.3.3. Distributional effects of the optimal reform

Despite large overall welfare gains, the optimal reform does not necessarily make all agents better off. Some agents may be worse off because they have to pay more tax to finance the additional DI benefits. In this subsection, I investigate the distributional effects of the optimal reform.

For this purpose, I define two measures. First, the lifetime utility gain for an agent with a lifetime history θ^W is defined as

$$\Delta(\theta^W) \equiv \frac{\sum_{t=1}^T \beta^{t-1} [\{u(c^*(\theta^t)) - v(n^*(\theta^t))\} - \{u(c^{kr}(\theta^t)) - v(n^{kr}(\theta^t))\}]}{\left| \sum_{t=1}^T \beta^{t-1} [u(c^{kr}(\theta^t)) - v(n^{kr}(\theta^t))] \right|}.$$

As (c^*, n^*) and (c^{kr}, n^{kr}) refer to the optimal and Korean allocations, the lifetime utility gain measures the percentage change in the lifetime utility due to the optimal reform.¹² Second, the annual resource gain for a lifetime history θ^W is defined as follows:

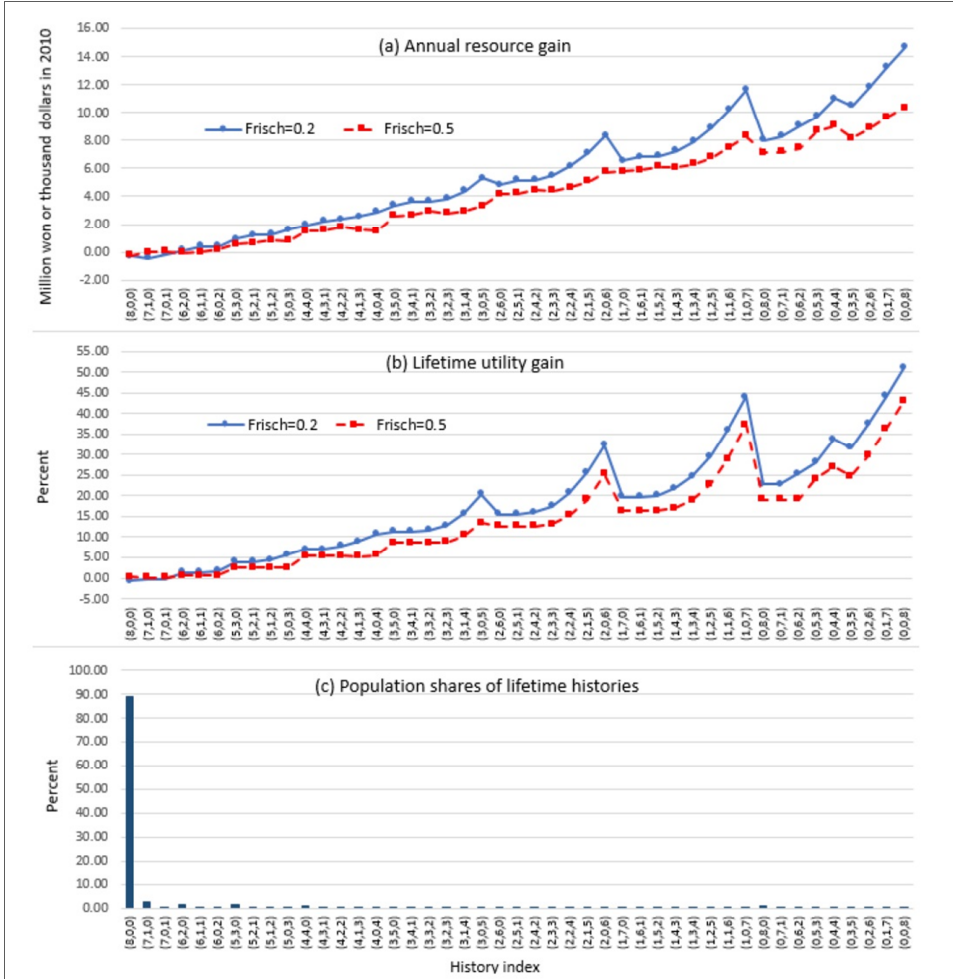
$$\Gamma(\theta^W) \equiv \left(\sum_{t=1}^T q^{t-1} \right)^{-1} \sum_{t=1}^T q^{t-1} [\{c^*(\theta^t) - y^*(\theta^t)\} - \{c^{kr}(\theta^t) - y^{kr}(\theta^t)\}].$$

The annual resource gain is the change in the average annual net consumption or the average annual government transfers due to the reform. A positive $\Gamma(\theta^W)$ is interpreted as an increase in government transfers following the optimal reform.

¹² The denominator of $\Delta(\theta^T)$ takes an absolute value because the level of lifetime utility can be negative.

Notice that $\sum_{\theta^w} \pi(\theta^w) \Gamma(\theta^w) = 0$ because the net consumption is equalized between the Korean and optimal allocation for welfare comparisons.

[Figure 7] Lifetime Utility Gain and Annual Resource Gain by Lifetime History



Note: The lifetime utility gain $\Delta(\theta^w)$ measures the percentage change in the lifetime utility if the optimal reform is implemented. Similarly, the annual resource gain $\Gamma(\theta^w)$ represents the change in the average amount of annual government transfers. $I(\theta^w) = (t_0, t_1, t_2)$ is the history index for an agent who is able in the first t_0 periods, partially disabled for the next t_1 periods, and fully disabled for the last t_2 periods of the working period.

$\Delta(\theta^w)$ and $\Gamma(\theta^w)$ in the calibrated model are shown in Figure 7 for all possible lifetime histories. Lifetime histories in the left end of the horizontal axis tend to be associated with late or less severe disability, whereas those in the right end with early or more severe disability. For example, the horizontal axis starts from

$I(\theta^w) = (8, 0, 0)$, agents with no disability throughout the working periods, and ends with $I(\theta^w) = (0, 0, 8)$, agents with full disability from the first period. With this in mind, I discuss the results for the baseline parameterization with the Frisch elasticity of 0.2. First, panel (a) of Figure 7 shows that annual resource gains are all positive except for agents who are able up to period 7 or equivalently age 59. In addition, annual resource gains tend to be larger for agents who become disabled earlier and/or more severely. These results indicate that able agents pay more taxes and disabled agents receive more transfers under the optimal system relative to Korea's DI system. As the weighted sum of annual resource gains is zero, the government essentially redistributes resources from able agents to disabled agents. In particular, the government can enormously increase transfers to disabled agents despite relatively small rises in taxes from able agents, according to panel (a) of Figure 7. For example, able agents with $I(\theta^w) = (8, 0, 0)$ should pay \$308 every period as additional taxes after the optimal reform but fully disabled agents with $I(\theta^w) = (0, 0, 8)$ can receive \$14,652 every period as additional transfers. This redistribution is possible because the population share of able agents far exceeds that of disabled agents, as in panel (c) of Figure 7.

This redistribution through the optimal reform substantially improves the welfare of disabled agents, but it reduces the welfare of able agents only slightly. With the additional transfers from the government, disabled agents can raise their consumption significantly and partially disabled agents can reduce excessive labor supply. All of these effects are evident in Figure 5, as already discussed. The effects are evidenced from the lifetime utility gains in panel (b) of Figure 7. Expectedly, although the agents whose annual resource gains are negative take utility losses (0.24% and 0.69%), all other agents benefit from considerable utility gains (1.43% to 50.86%) relative to the lifetime utility in the Korean allocation. These utility gains account for the substantial equity gain, that is, 73.4% of total welfare gains, from the optimal reform.

This analysis has an interesting implication for the direction of a policy reform on Korea's DI system. The government can improve social welfare greatly by collecting slightly more taxes from able agents and redistributing the tax revenue to disabled agents. This policy can make disabled agents considerably better off because they can receive enormous amounts of additional transfers, which are possible due to the asymmetry in the population share between able and disabled agents. Moreover, such redistribution is budget neutral to the government in that it does not require any additional government funds to implement the policy. Considering a policy mix that can achieve this kind of redistribution is worthwhile, for example, a large increase in type 1 and 2 disability benefits and a significant rise in disability pension benefits from the NPS along with a moderate increase in taxes from able agents.

6.4. Robustness Checks

6.4.1. Alternative parameterization

Thus far, I analyze the results of the quantitative welfare analysis with the baseline parameters. However, uncertainty about the true values of parameters such as ε and κ exists, and the main results can be sensitive to changes in those parameters. In this subsection, I examine the robustness of the baseline results in the models with alternative values of ε and κ .

In the baseline model, κ is set to 0.5 based on the difference in wage rate between able and disabled agents in the data. However, that κ is actually higher than 0.5 is possible, but disabled agents receive lower wages due to disadvantages or discrimination in the labor markets. Thus, I recalibrate the model with $\kappa = 0.7$ instead of 0.5 and analyze the sensitivity of the baseline results to this change. In column [4] of Table 2, efficiency gain Φ^{nr} and equity gain $\Phi^* - \Phi^{nr}$ are slightly smaller in the calibrated model compared with those in the baseline model. Intuitively, with higher productivity, agents do not experience a large drop in consumption after partial disability because they can still earn enough labor income. For this reason, partially disabled agents are relatively well off under Korea's DI system, which explains the smaller equity gain. Moreover, some partially disabled agents choose to work until age 64, unlike in the baseline model, due to the increased productivity. Thus, the inefficiency due to their early retirement and excessive labor is reduced, which implies a smaller efficiency gain from the optimal reform.

As for the Frisch elasticity, the baseline model adopts $\varepsilon = 0.2$ because it can match key moments on the labor hours and earnings most closely. This value, however, is close to the lower bound in the range of the standard values of the Frisch elasticity in the literature. Therefore, I consider two alternative values of ε here (i.e., 0.5 and 0.8) to investigate the impact of raising ε . The welfare gains and retirement ages in these cases are presented in columns [2] and [3] of Table 2, which indicate that both Φ^* and Φ^{nr} are much larger than in the baseline model, especially in the model with $\varepsilon = 0.5$. The optimal and NR reforms will generate even more significant welfare gains if labor supply is relatively elastic. This result strengthens the main finding on the welfare effects of the reforms as the welfare gains are smallest in the baseline model.

Φ^* and Φ^{nr} are larger when labor supply is more elastic, because as indicated in columns [1]–[3] of Table 2, Φ^* goes up by almost as much as Φ^{nr} when 0.5 or 0.8 replaces 0.2 as the value of ε . The increase in the total welfare gains can be attributed almost entirely to the increase in the efficiency gain. This result suggests that Korea's DI system will create greater inefficiency in the resource allocation in the model with relatively high ε . One symptom of such inefficiency in columns [1]–[3] of Table 2 is that the discrepancies between retirement ages in Korea and

the optimal retirement ages are smallest when $\varepsilon = 0.2$, larger when $\varepsilon = 0.8$, and largest when $\varepsilon = 0.5$. As early retirement is a clear indication of inefficiency in the labor allocation in this model, that Φ^{nr} is smallest for $\varepsilon = 0.2$, larger for $\varepsilon = 0.8$, and largest for $\varepsilon = 0.5$ is expected.

The Frisch elasticity affect the early retirement. A rise in ε makes labor supply n_t more sensitive to labor productivity ϕ_t . Given the hump-shaped productivity profiles in Figure 2, the increase in ε tends to raise labor supply in young and middle ages and reduce labor supply in old ages, as confirmed in panel (a) of Figure 4. In particular, this effect can be adequately strong to cause agents to retire earlier than age 65 or period $W+1$, if ε is large and/or ϕ_t is low late in the working periods. For this reason, retirement ages tend to decrease with ε in the Korean and optimal allocations in Table 2. This tendency is more pronounced in the Korean allocation because of labor disincentives due to DI programs and income tax. In particular, when ε increases from 0.2 to 0.5, retirement ages fall in the Korean allocation, whereas the optimal retirement ages remain to be 65. As the gaps in retirement ages widen, the Korean allocation becomes more inefficient than the optimal allocation, and the efficiency gain from the optimal reform, Φ^{nr} , increases substantially. However, when ε increases further to 0.8, the optimal retirement ages also decline, whereas those in the Korean allocation remain almost the same. These changes narrow the gaps in retirement ages between the two allocations and the efficiency gain Φ^{nr} declines.

The change in ε also affects the distribution of resources and utility across agents. As depicted in Figure 7, the increase in ε to 0.5 reduces the degree of redistribution in the optimal reform although it leaves the pattern of redistribution unaffected. Specifically, in panel (a) of the figure, the annual resource gain $\Gamma(\theta^W)$ is higher for agents who are able up to period 7 or age 59 but lower for all of the other types of agents in the model with $\varepsilon = 0.5$ than in the baseline model. For intuition, labor distortions due to taxation tend to increase with the labor elasticity. To reduce such labor distortions, the government reduces taxes from the able agents when ε is relatively high, which raises their annual resource gains. On the contrary, the smaller tax revenue forces the government to decrease transfers to disabled agents, which explains the fall in their annual resource gains. When $\varepsilon = 0.5$, a smaller amount of resources is redistributed from able agents to disabled agents, as clearly shown in panel (a) of Figure 7. The change in the degree of redistribution can explain the effects of ε on lifetime utility gains $\Delta(\theta^W)$, which is displayed in panel (b) of Figure 7. Lifetime utility gains for agents who are able up to period 7 or age 59 are larger in the model with $\varepsilon = 0.5$ because their additional tax payments in the optimal reform decline. Similarly, lifetime utility gains for all of the other types of agents are smaller with $\varepsilon = 0.5$ as additional transfers to them in the optimal reform decrease.

Panel (b) of Figure 7 presents another interesting effect of the optimal reform: if

$\varepsilon = 0.5$ in the model, then the optimal reform leads to a Pareto improvement in the sense that the lifetime utility gain $\Delta(\theta^w)$ is strictly positive for all possible lifetime histories. This result appears puzzling given that some types of agents should pay more taxes as a result of the optimal reform. Nevertheless, increasing lifetime utility despite additional tax burden is possible because the optimal reform generates substantial efficiency gains for these agents. As evidenced in Table 2, when $\varepsilon = 0.5$, early retirement and labor distortions are so prevalent in the Korean allocation that even the agents who never have any disability retire earlier than they will in the optimal allocation. In this calibrated model, the utility gain from the improved efficiency can more than compensate for the utility loss due to the additional taxes in the optimal reform. the optimal reform can consequently improve the lifetime utility of all agents regardless of lifetime history. This finding indicates that if labor supply is sufficiently elastic, then the redistribution from able to disabled agents can be politically feasible because it benefits all types of agents provided that an appropriate tax reform is implemented concurrently.

In sum, the analysis thus far suggests that the baseline results remain valid even in the model with alternative values of ε and κ . Although the change in κ does not seem to overly affect Φ^* and Φ^{nr} , the increases in ε tend to raise Φ^* and Φ^{nr} significantly. Nevertheless, the baseline value of labor supply elasticity continues to lie within the range of micro estimates in the literature, and the optimal reform can generate non-negligible welfare gains of $\Phi^* = 1.17\%$ even in the baseline model.

6.4.2. Model with public information

All of the analyses so far are based on the assumption that the disability status is privately observed. Although this assumption is the standard in the DI literature, the validity of the assumption depends crucially on the accuracy of the medical screening processes for Korea's DI programs. Given the lack of the data on their effectiveness, I examine the sensitivity of the baseline results to the observability of the disability status. For this purpose, I recalculate the welfare gains with the alternative assumption that disability types are publicly observed.

Column [5] of Table 2 presents the results of the quantitative analysis in the case that disability is public information. First, $\Phi^* = 1.13\%$ in this case and is almost the same as $\Phi^* = 1.17\%$ in the baseline model. Overall welfare gains from the optimal reform are similar whether disability types are observed privately or publicly. Hence, the baseline results seem to be maintained even if disability types are publicly observed.

However, the efficiency gain Φ^{nr} is slightly lower in the model with public information on disability than that in the baseline model. If disability types are publicly observed, agents cannot pretend to be fully disabled, and, thus, all agents should work as long as possible even in the Korean allocation, as shown in column

[5] of Table 2. Without early retirement, labor distortions in the Korean allocation are likely to be limited, which means that the efficiency gain from correcting them is also expected to be small. Consequently, Φ^{nr} is relatively small when the disability status is publicly observed.

By contrast, the equity gain $\Phi^* - \Phi^{nr}$ is slightly larger in the model with public information on disability compared with that in the baseline model. For intuition, if disability types are publicly observed, then the planner's problem does not include IC constraints (6), which in effect restrict redistribution from able agents to disabled agents. In this case, the planner can redistribute without any restriction from able agents to disabled agents, thereby maximizing the equity gain. For this reason, the optimal reform will generate larger equity gain if disability types are publicly observable.

VII. Concluding Remarks

In this paper, I develop a framework through which DI systems can be quantitatively evaluated. As opposed to the standard papers in the literature, this paper takes account of full and partial disability. In the model, agents can be able, partially disabled, or fully disabled, and their disability statuses change over their life cycles. With the framework, I first characterize the optimal allocation. In particular, I examine the effects of partial disability on the intertemporal allocation of consumption and intratemporal allocation of consumption and labor.

I also calibrate the model to the Korean economy to analyze the welfare effects of Korea's DI system in which partial and full disability are covered. Specifically, I quantify the welfare gains from a reform that replaces Korea's DI system with an optimal system. In the baseline model, such a reform can yield significant welfare gains that amount to a 1.17% increase in consumption for all agents in the economy. Such a reform benefits disabled agents, often substantially, but hardly hurts able agents. As a result, the lifetime utility gaps between able and disabled agents fall, and agents become better insured against disability risk.

In addition, I recalibrate the model with alternative assumptions as robustness checks. Even if labor supply is more elastic or partial disability is less damaging, the optimal reform can still generate significant welfare gains and enable partially and fully disabled agents to better deal with the income loss due to disability. In particular, in the case that the Frisch elasticity is 0.5, the labor distortions are so severe under Korea's DI system that even able agents will prefer the optimal system to the Korean system although they should pay more taxes under the optimal system. In this case, the optimal reform leads to a Pareto improvement because it makes all types of agents better off. This result suggests that for relatively elastic labor supply, the redistribution that attains the optimal allocation can be politically

feasible as all types of agents in Korea will support it. I also relax the assumption that disability is observed privately as the second robustness check. Total welfare gains from the optimal reform remain large in the model with public information on disability although the relative shares of the equity and efficiency gains change slightly.

Together, the findings suggest room for improvement in Korea's DI system. Agents tend to experience a considerable drop in consumption when they are hit by a disability because the current DI system does not provide them with sufficient support. This problem is especially serious for agents who become disabled relatively early in their life cycles and/or more severely because they do not have adequate time to accumulate wealth to finance consumption. An obvious direction for policy reform is a substantial rise in benefits for disabled agents. Such a reform can improve welfare if larger benefits are given to young disabled agents than old disabled agents with the same severity of disability. This kind of age-dependent DI program at least warrants consideration.

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