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An Agent-Based Approach to Simulating the Minimum Wage Market

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Abstract

This paper seeks to identify and describe the economic impacts of adjusting the minimum wage on employment. The approach taken is constructing an agent-based simulation using the well-known software suite NetLogo. The simulation models business and consumer behavior through a set of governing economic principles, yet also provides randomization to more accurately account for occasional outliers and human irrationality. The results of the simulation indicate relatively small changes in employment among minimum wages between $7.25 and $10.00, with a gradual decrease thereafter.

Contents

1 Introduction

1.1 Background and Related Work

The minimum wage is one of the most popular government-enforced price floors. However, the level at which it is most effective has long been debated, introducing many questions. Does raising the minimum wage *actually* yield net positive results? If so, *how much* should it be increased? Many economists cite that by raising salaries, consumption will increase and negate companies' higher costs. Others claim that unemployment will grow or that prices will largely increase, essentially counteracting the entire purpose behind raising the minimum wage. In truth, the effects of altering the minimum wage are manyfold and influenced by many factors that are location-specific.

For instance, a recent NPR interview [5] revealed that professors Srikant Devaraj, Subir Chakrabarti, and Pankaj Patel had conducted a surprising analysis on the effects of Seattle's newly-adjusted $15 minimum wage in restaurants. According to the interview, their research found that despite substantial gains for a large number of minimum wage workers, health violations increased. An explanation for this unintuitive phenomenon could be that restaurants are combating increased wage costs by trimming hours, thus reducing worker morale and in turn sanitation [5].

Although only one study, Devaraj, Chakrabarti, and Patel's work illustrates the wide range of ramifications possibly resulting from minimum wage regulation. In fact, it is this very complexity that prompted extensive investigation into the field. Despite producing contradictory results [6], early research examined the impacts on teenagers, as they represented a sizable percentage of the workforce, but their relevance today has greatly decreased [4]. Most economists have instead focused recently on restaurant workers [4].

Further, models are ubiquitous in economics due to their ability to better describe observed mathematical relationships and predict future phenomena. The economic principles underlying the model in this paper are closely based on the minimum wage model developed by the UC Berkeley IRLE Minimum Wage Research Group [4], which specifically analyzes the employment repercussions of incrementally raising the minimum wage in New York State to $15 by 2021. Their focus was primarily on the design and statistical verification of the model, utilizing much of the datasets collected in [1]. Fig. 1 below illustrates the qualitative specifics of their model.

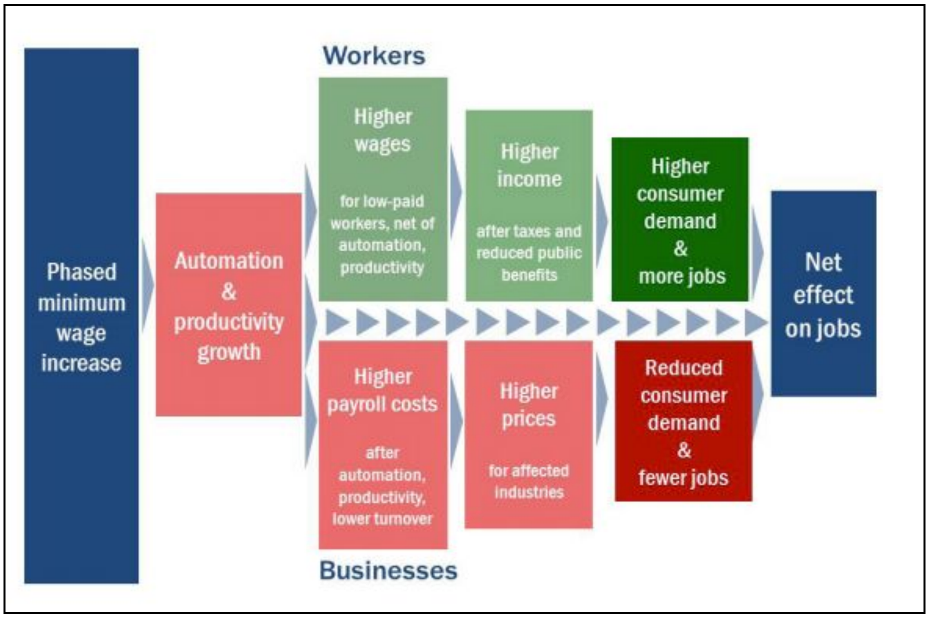

Fig. 1. UC Berkeley IRLE Minimum Wage Model [4, p. 14].

Moreover, over the past several years, computers have significantly aided the verification and development of models. With economics, some research has been directed towards this movement. For instance, Benirschka and Koo [3] implemented a comprehensive program to simulate their model of world wheat policies and trading. Nevertheless, efforts specifically aimed at computerizing minimum wage models, especially from an agent-based perspective, are virtually nonexistent, offering an exciting research opportunity.

1.2 Economic Foundations

In order for the model to provide relevant results, it must simulate how people and businesses behave in real life. As such, I have based the model significantly on the economic principles underlying the minimum-wage job market discussed in [4].

The first major economic foundation is the *income effect*. As the name suggests, this corresponds to how individual consumption is affected by an adjustment to one's income. As Fig. 1 illustrates, when consumers earn more, they typically respond by purchasing more goods, which increases business revenue. As such, this is an extremely important principle to consider when adjusting the minimum wage. Although employers might have an increase in costs from higher wages, part of the costs will be offset from a spike in consumer demand. The exact increase in consumer demand will depend on the individual's demand elasticity.

Of course, it is vitally important to realize that individual consumption will gradually level out. In other words, there is a limit to how much one person will buy. For example, if you were to increase an individual's annual income by 10%, their consumption might increase by 20%. However, another increase in income by 10% might only result in them consuming 10% more. This phenomenon is due to the law of diminishing marginal utility, which intuitively states that an individual's satisfaction from consuming one more good gradually decreases. In the model, it is important to account for this to prevent unrealistic consumption increases.

The second major economic foundation is the *scale effect*. As seen in Fig. 1, the *scale effect* corresponds to a firm's price increase followed by reduced consumer demand. This is a fairly straightforward concept. When costs increases, many businesses respond by increasing prices. However, doing so will generally result in decreased consumer demand since individuals will not want to buy as much at a higher price, although the exact amount again depends on consumer demand elasticity.

The final major economic foundation to consider is the *worker effect*, which indicates how workers respond to minimum wage increases. When the minimum wage is increased, worker productivity and happiness obviously rise. As such, workers generally stay employed at the same location longer, reducing hefty turnover costs for businesses and thus increasing profits.

1.3 Goals

The primary goal of this paper is to determine how the employment level varies with the minimum wage and what that indicates for economic policies. For instance, if a minimum wage of $7.25 and $10.00 produce a relatively similar level of employment, it might be reasonable to enforce the latter since it provides a substantial increase in earnings.

The second goal of this paper is to present an alternative method to examining the economic effects of the minimum wage. Nearly all economic models are top-down in that they seek to describe economic effects through aggregate data or relationships that are already known. The agent-based model in this paper, however, takes a bottom-up approach. It seeks to examine economic effects by starting with firm and consumer decisions on a micro-level. The major advantage to this approach is that it can account for human irrationality by introducing randomization. For example, when consumers purchase goods, they might follow the trend of buying less at higher prices, but there might be *some* consumers that find the price irrelevant and thus purchase the same amount. In addition, consumers' tastes might prompt them to alternate between stores from time to time. Fortunately, the agent-based model can simulate this by randomizing consumer decisions to a certain extent.

2 Approach

2.1 Tools

NetLogo [8] is the software used to develop the minimum wage model. It is an agent-based modeling environment that allows the user to easily code their own simulation. The user is able to define their own agents, such humans or houses. Each simulation tick, which can represent any unit of time, the agents individually update their own variables based on their pre-defined behavior. Not to mention, simulation parameters can be modified to adapt the model to a variety of scenarios and graphs of data can be exported to Excel for further analysis.

2.2 Design

Overview

To simulate the minimum wage market while keeping the model as simple as possible, I focused solely on the interactions between the two groups in question: consumers and minimum-wage-employing institutions. Although other institutions that do not employ minimum wage workers might still be affected from increased consumer demand, their workers' wages are not tied to the minimum wage. As such, they are not relevant since they provide no insight into how minimum wage adjustments affect the employment of low-earning individuals specifically.

Further, as consumers and firms interact over time, businesses will adjust their employment levels and prices and customers will alter how much they purchase until an equilibrium is reached.

Agents

As mentioned, this simulation contains two agents: consumers and businesses. First, each consumer contains the following variables:

1. *quantity-demanded*: Keeps track of how many goods the customer wishes to buy and is a randomly generated number between 0 and 10. Some individuals might visit the firm and not wish to buy anything regardless of the price, while others might be in the mood to buy a fair amount. The randomization accounts for the wide range of possibilities.
2. *minimum-wage-worker?*: A boolean variable that, as the name suggests, keeps track of whether a consumer is a minimum wage worker themselves. If the

consumer is a minimum wage worker, their demand might adjust based on their income. Consumers who are not minimum wage workers will not alter their demand since their income is independent of the minimum wage.

The second agent, a business, contains the following variables that determine its behavior:

1. *price*: Varies with each firm and determines the price at which the firm sells one good. In addition, it is the price *after* the business accounts for costs, which simplifies the calculation of production costs. For example, if it costs a business $1 to supply a good that sells for $4, the *price* will be $3.
2. *weekly-revenue*: Keeps track of how much consumers have paid over one week.
3. *running-profit*: Keeps track of a firm's net profits and thus provides the information necessary to make business decisions, such as firing employees or increasing prices.
4. *num-customers*: Keeps track of the number of customers that visit each institution. To give a visual effect, the color of each institution is scaled based on how many customers visit it.
5. *num-workers*: Keeps track of how many workers are employed at each business. The level of employment is thus the sum of this variable over all businesses.

Parameters

The simulation utilizes several parameters for its initialization and agent behavior. The following list details each one:

1. *ticks*: Corresponds to one model loop and is automatically provided by NetLogo.
2. *num-businesses*: The number of businesses created in the simulation.
3. *num-workers-per-business*: The number of workers each business initially employs in the simulation.
4. *consumer-spawn-number*: The number of customers that visit the businesses each tick.
5. *minimum-wage*: The minimum wage that employers must pay to each employee.
6. *base-price-per-good*: The initial price that each employer sells their items at.
7. *worker-turnover-cost*: The cost incurred when a worker quits. When this happens, firms will have to hire new workers, which means more money and time spent on training. Not to mention, productivity might temporarily decrease from reduced morale.

8. *percent-consumers-on-minimum-wage*: Determines what percentage of the consumers that visit businesses are minimum wage workers. This is important since minimum wage workers' demand will increase when their income rises.
9. *worker-happiness-threshold-in-months*: Determines how long a typical employee will work at the respective minimum wage before switching jobs to seek a higher income.
10. *business-weekly-operating-costs*: The total costs of running a business for one week. These costs include, but are not limited to, rent, equipment, insurance, and utilities.

Environment

Fig. 2 below shows the resulting simulation environment with the appropriate parameters, buttons, and visual display.

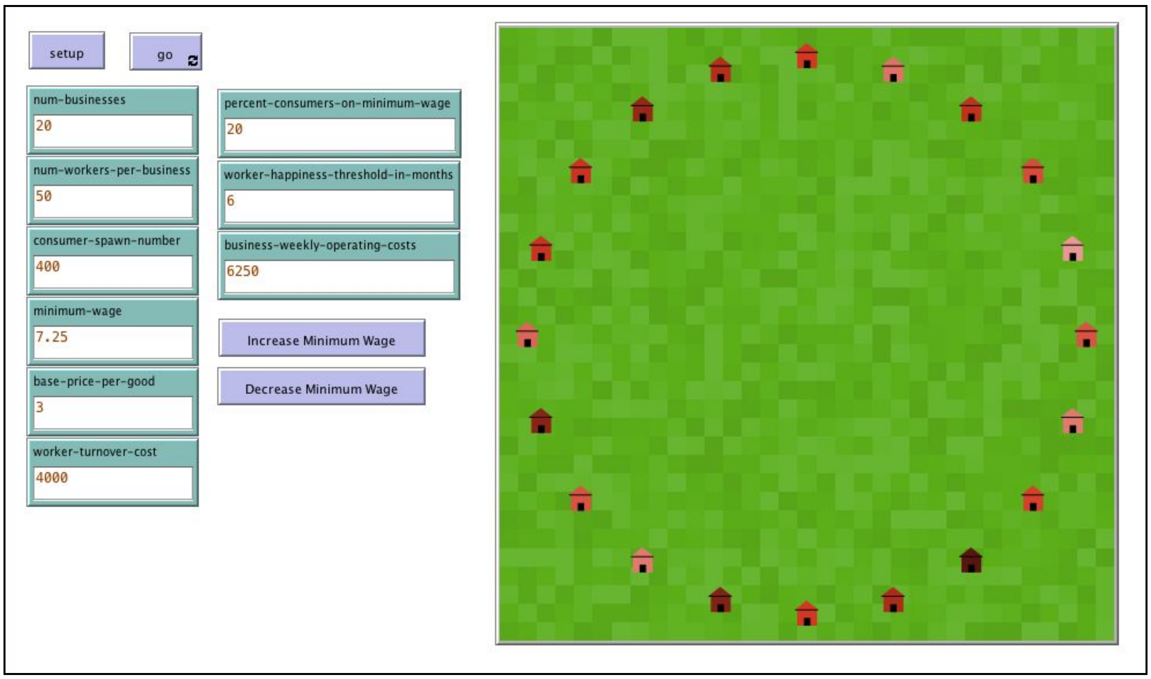

Fig. 2. Simulation Environment.

Each house represents a business and its color indicates how many consumers have visited in a given tick. The darker the shade of red, the more customers. As the colors in Fig. 2 illustrate, most businesses share roughly the same number of consumers, with a few exceptions.

2.3 Parameter Initialization

Given that the model is intended to accurately simulate a minimum wage market, it is important to provide realistic parameter values. However, since nearly all economic data is aggregate-based, most parameter values were constructed using conventional knowledge. The following list details the parameter initialization:

1. *ticks*: I let one tick correspond to one hour in real-time. Anything less requires too many loops to get useful data and anything more significantly slows down the model due to the increased space requirement for creating consumer agents.
2. *num-businesses*: 20
    a. The number of businesses can be any number. I chose 20 since it is not too computationally expensive, yet large enough to provide meaningful data.
3. *Num-workers-per-business*: 50
    a. I chose a number that seemed natural. However, the exact value choice is relatively unimportant since the number of workers per business will always reach the same equilibrium.
4. *consumer-spawn-number*: 400
    a. This number is difficult to calculate since the amount of customers will widely vary from business to business and largely depend on the population size. However, it is reasonable to assume that a standard business might serve 200-300 customers per day. Given that stores are generally open 12 hours a day, the number of customers per hour will be around 15-25. With 20 individuals visiting a store per hour on average and 20 businesses in this simulation, 400 consumers must be populated. Of course, randomization helps account for special cases. For instance, in one tick, 10 people might visit a business, but then 40 people might visit the next tick. This accurately simulates real life, as consumer volume increases at certain times of the day and decreases during others. Not to mention, consumer expectations and preferences might vary with each store depending on the time of year or weather.
5. *minimum-wage*: 7.25
    a. This is the current federal minimum wage.
6. *base-price-per-good*: 3
    a. This number was also relatively difficult to calculate since store prices will largely depend on what the store sells. If the business is fast food, consumers might spend $7, yet spend $25 at a retail store. Since

consumers will demand between 0 and 10 goods, they will spend between $0 and $30 at an initial base price of $3, which is a realistic figure.

7. *worker-turnover-cost*: 4000
    a. The worker turnover cost depends on training, interviewing, and adjustments to employee morale specific to each business. That being said, $4,000 is a reasonable amount, given that the cost is approximately 20% of an employee's annual salary [2].
8. *percent-consumers-on-minimum-wage*: 20
    a. Since minimum wage workers themselves are more likely to shop at minimum-wage-employing businesses, such as fast food restaurants, than higher-income customers due to cheaper prices, it is important to note that they will make up a decent part of the consumer base. However, minimum wage workers are still only a small portion of the population [7]. As such, 20% is an appropriate number.
9. *worker-happiness-threshold-in-months*: 6
    a. At an initial minimum wage of $7.25, it seems perfectly reasonable that a few workers might leave every 6 months to find better paying jobs. However, other values, such as 7 or 10 months, work as well since worker happiness can take on a wide range of values depending on the individual worker's family or financial situation.
10. *business-weekly-operating-costs*: 6250
    a. There are numerous costs associated with a business: utilities, advertising, possible severance pay, transportation, inventory space, unplanned inventory changes, rent, loans, equipment, insurance, maintenance, training, and so forth. Given the long list of expenses and the fact that each business typically serves a few hundred customers every day, a monthly operating cost of $25,000 certainly seems realistic, yielding a weekly operating cost of $6,250.

2.4 Workflow

The simulation has a relatively straightforward workflow, as illustrated by Fig. 3 below.

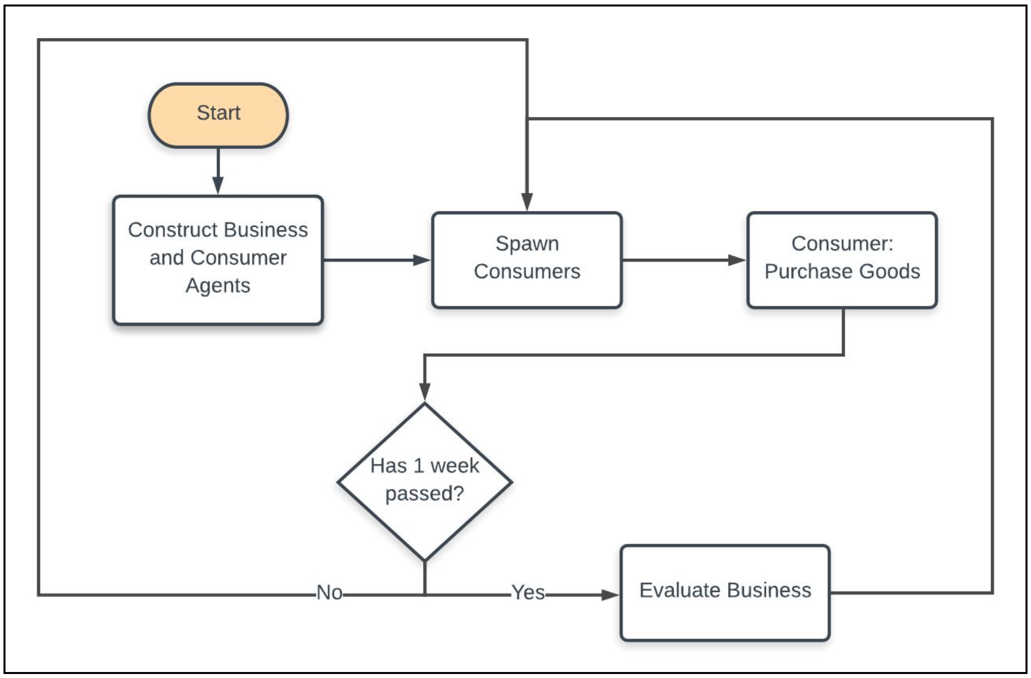

Fig. 3. Simulation Workflow.

The first major step in the simulation is setting up the environment, which is accomplished by constructing the business and consumer agents and initializing any member variables to proper values. The second major step is spawning the consumers. This is accomplished by simply "assigning" each consumer to a random business.

The third major step is the consumer purchase, which requires a bit more sophistication. Each consumer starts with a randomized amount of quantity demanded between 0 and 10. However, this will change based on the price and the individual's income. To account for the former, the consumer's quantity demanded is decreased by an amount depending on the difference between the business's price and the base price that the simulation started with. To simulate different price elasticities of demand, a multiplier is randomly generated and applied to the price difference. Moreover, to model the income effect, if the consumer in question is a minimum wage worker (i.e., their income is tied to the minimum wage), their quantity demanded is increased by a random amount proportional to `log(minimumWage)`. Thus, the higher the minimum wage, the more goods the customer will demand. Of course, due to the law of diminishing marginal utility, the increase in their demand will begin to slow. The logarithmic function perfectly models this.

The final phase is business evaluation, which occurs every week in the simulation. The evaluation is relatively intuitive and performs the following procedure:

1. Calculate operating, labor, and turnover costs.
2. Calculate weekly profit from total consumer spending and total costs.
3. Determine running profit.
    a. If the running profit is negative, then either fire a worker or lower prices.
    b. If the running profit is positive, then either hire a worker or raise prices.

The first aspect of the procedure to notice is that businesses make decisions based on their running profits. It would be unrealistic for firms to base their decisions on weekly profits since weekly profits do not give the entire picture of a business's financial situation. The second aspect to notice is how a firm responds to their running profit. If a business has a positive running profit, they realistically respond by hiring more employees to expand their business or increase their prices to boost profits and keep up with consumer demand. Alternatively, if a firm has a negative profit, they generally respond by either lowering prices or firing employees to decrease costs. The justification for firms lowering prices is that their negative profits could be a result of overcharging. Not to mention, firms will certainly not increase their prices in times of financial hardship since doing so could lead to reduced consumer demand and lower revenue.

Finally, although not depicted in Fig. 3, the simulation provides buttons to alter the minimum wage. When increased, worker happiness will rise, reducing turnover frequency, and some firms will pass the costs onto consumers through increased prices. On the other hand, when the minimum wage is decreased, worker happiness will fall, increasing turnover frequency.

3 Results

To begin, Fig. 4 below illustrates the employment changes resulting from a *gradual* minimum wage increase from $7.25 to $10.00 over a period of approximately 5.5 years.

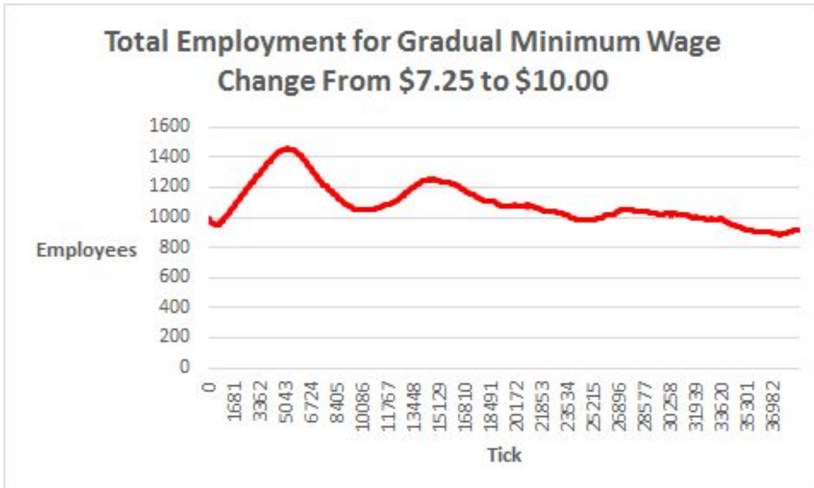

Fig. 4. Minimum Wage Employment Data 1.

Although the employment level decreases, the change is not considerable. Since employees experience a substantial increase in their earnings from $7.25 to $10.00, the relatively minor decline in employment might be tolerable.

Furthermore, Fig. 5 below captures the effects resulting from *immediately* increasing the minimum wage from $7.25 to $10.00, which occurs around tick 16,401.

Fig. 5. Minimum Wage Employment Data 2.

Quite clearly, after a sudden minimum wage increase, employment immediately decreases by a substantial amount. In fact, employment falls below 800, whereas it never does in Fig. 4. Although somewhat intuitive, this strongly indicates that minimum wage adjustments should be implemented through small increments over a large time period in order to avoid adverse employment repercussions. Fortunately, many current minimum wage regulations utilize this method. For instance, New York is increasing the state minimum wage to $15.00 over 5 years by 2021 [4].

Finally, Fig. 6 below demonstrates the effects of gradually increasing the minimum wage from $7.25 to $30.00 over a period of approximately 10 years.

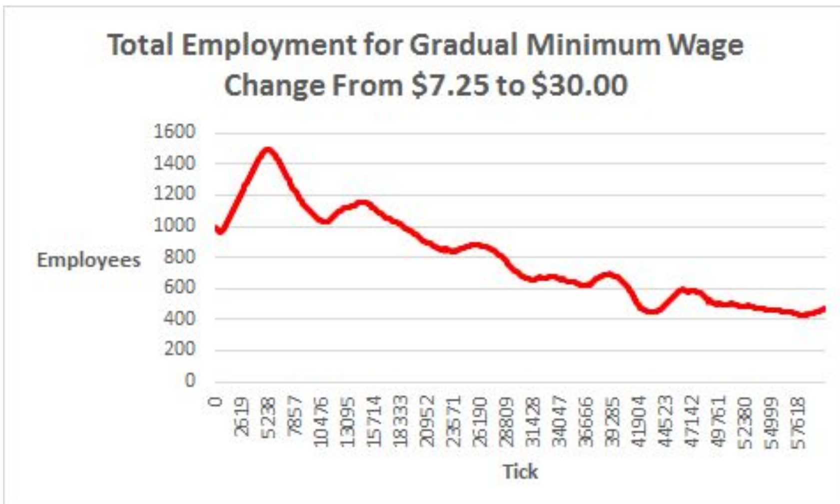

Fig. 6. Minimum Wage Employment Data 3.

The results are quite astonishing, as they indicate that employment will progressively decrease as the minimum wage increases, contradicting any conjectures that employment might increase slightly or remain virtually unchanged from minimum wage increases, ceteris paribus. Another intriguing result is that employment does not plummet at absurdly high minimum wages, such as $30.00. However, this is because the simulation does not account for substitution effects since they are relatively negligible at reasonable wage levels [4]. At an extreme minimum wage of $30.00, it is highly probable firms would immediately invest in automation or skilled labor.

4 Conclusions

In this paper, an alternative method for analyzing the impact of minimum wage increases on employment is presented. The method consists of the design and implementation of a bottom-up, agent-based model using NetLogo that simulates the minimum wage market through realistic consumer-business interactions. The results of the simulation indicate that employment will steadily decline as the minimum wage rises. However, employment variations within the $7.25-$10.00 range are relatively minor and perhaps justifiable by the significant increase in employee earnings.

It is important to note that the simulation does *not* offer an optimal minimum wage level for the entire United States. For some states, such as California or New York, a minimum wage of $15 might be practical because of larger populations and necessary due to the higher cost of living. For other states with lower costs of living or smaller populations, however, such as Arkansas or Kansas, a $10 minimum wage might suffice as an acceptable income.

Rather, the simulation provides useful data as to how employment in general varies with the minimum wage, allowing economists to concentrate on how to mitigate or substantiate inevitable job losses from future minimum wage adjustment policies.

For future goals, I plan to continue developing the minimum wage model for better accuracy by including changes to employee taxes and benefits, more thoroughly simulating production costs and inventory management, and providing other realistic consumer trends such as migration towards firms with lower prices.

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References

[1] D. Cooper, “Raising the New York State Minimum Wage to $15 by July 2021 Would Lift Wages for 3.2 Million Workers”, Briefing Paper 416, Economic Policy Institute, 2016.

[2] H. Boushey and S.J. Glynn, "There Are Significant Business Costs to Replacing Employees", Washington, DC: Center for American Progress, 2012.

[3] M. Benirschka and W.W. Koo, “World Wheat Policy Simulation Model: Description and Computer Program Documentation”, Agr. Econ. Rep. No. 340, Department of Agricultural Economics, North Dakota State University, Fargo, 1995.

[4] M. Reich, S. Allegretto, K. Jacobs, and C. Montialoux, “The Effects of a $15 Minimum Wage in New York State”, Institute for Research on Labor and Employment, University of California, Berkeley, 2016.

[5] NPR (2017, Sep. 13). *How The Minimum Wage Affects Restaurant Hygiene* [Interview]. Accessed on: Sep. 25, 2017. Available: http://www.npr.org/2017/09/13/550607377/how-the-minimum-wage-affects-restaurant-hygiene

[6] S. Allegretto, A. Dube, and M. Reich, “Do Minimum Wages Really Reduce Teen Employment? Accounting for Heterogeneity and Selectivity in State Panel Data”, *Industrial Relations*, vol. 50, no. 2, pp. 205-240, April. 2011.

[7] “Characteristics of minimum wage workers, 2015”, Report 1061, U.S. Bureau of Labor Statistics, 2016.

[8] https://ccl.northwestern.edu/netlogo/